the Acid Deposition Research Program

BIOPHYSICAL RESEARCH

OVERVIEW OF THE EMISSION DATA: EMISSION INVENTORY OF SULPHUR OXIDES AND NITROGEN OXIDES IN ALBERTA

by:

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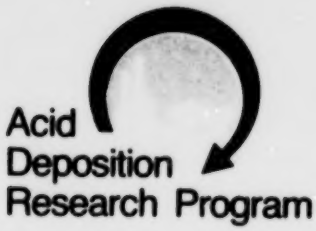

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Emission Inventory

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***Detailed data compilations, of technical interest.**

EMISSION INVENTORY OF SULPHUR OXIDES AND NITROGEN OXIDES IN ALBERTA

VOLUME 1
OVERVIEW OF THE EMISSION DATA

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EXECUTIVE SUMMARY

Air quality predictions play an important role in solving existing air pollution problems and in evaluating the potential impact of proposed emission sources. To predict air quality properly at a given location, it is necessary to identify all emission sources that will have significant impact at that location. Furthermore, the atmospheric pollutants that are emitted by these sources must be identified and quantitatively characterized. Once the air quality predictions have been made, it is desirable to have some historical air quality data for comparison. An efficient means of obtaining this information is through the use of detailed emission inventories and an inventory of air quality monitoring stations.

With specific regard to acid-forming emissions (i.e., sulphur dioxide and nitrogen oxides), it has been recognized that existing inventories for Alberta are either incomplete or do not provide sufficient detail to permit the investigation of specific regions within the province. Therefore, as part of the Alberta Government/Industry Acid Deposition Research Program (ADRP), three comprehensive inventories have been developed, namely:

- a sulphur dioxide (SO_2) emission inventory,
- a nitrogen oxides (NOx) emission inventory, and
- an inventory of air quality monitoring stations.

The basic objectives in developing these three inventories have been:

1. To identify all noteworthy anthropogenic sources of SO_2 and NOx emissions in Alberta. This includes all SO_2 and NOx emission sources that are licenced by the Alberta Government to operate under the Clean Air Act, sour oil batteries that emit more than 0.2 tonnes/day (t/d) of SO_2, and the following NOx emission sources:

   - industrial engines with a maximum rated power output of greater than 100 kW,
   - urban centres, and
   - the major portions of high traffic highways in the province (Highways 1, 2 and 16).

   Licenced industrial sources include natural gas processing facilities, oil refineries, oil sands and heavy oil recovery facilities, fertilizer and chemical plants, power generation plants, pulp and paper plants, and cement plants.

Sources were identified on the basis of 1985-86 records available from government agencies and existing inventories. Emissions were estimated based on 1984 production data. Limited verification and updating of sources occurred in 1987.

2. To characterize each emission source, as appropriate, with respect to:

   - type of emission (i.e., NOx or SO_2),
   - geographic location (i.e., Legal Subdivision, Section, Township, and Range),
   - environmental setting (surrounding vegetation, ecoregion type),
   - physical characteristics (e.g., stack height and diameter),
   - maximum licenced emission rate (where applicable), and
   - emission characteristics (i.e., exit velocity, exit temperature, average emission rate, temporal variations and emission rate precision).

3. To conduct a limited NOx source sampling program in order to develop Alberta-specific NOx emission factors for natural gas fueled reciprocating and turbine engines, and to assess the importance of waste gas incinerator units as NOx emission sources.

4. To identify all air quality monitoring stations at which ambient levels of NOx and/or SO_2 are measured.

5. To computerize the inventories so that information may be easily retrieved and the inventories easily updated.

The three inventories are intended to serve as a source of information that will assist investigators in estimating the average rates of NOx and SO_2 emission in Alberta, and the distribution of these emissions by geographic area, industry type, and environmental setting (ecoregion). The inventories will also be useful in predicting changes in emission levels by the current emission sources due to future changes in production levels (i.e., forecasting future emissions). Administrative information, including operator name, approvals and regulatory information, is also provided for each industrial source to facilitate source-specific research.

To enable use of the emissions data base in emissions forecasting and to allow prediction of emission rates from sources for which actual emission data are unavailable, emission rates for each of the sources inventoried have been estimated based on the use of emission factors. Emission factors are average values that relate the emission of NOx or SO_2, as appropriate, to a suitable operating parameter of the sources (generally, process production data).

The estimated emission rates presented in the emissions data base are expressed as average daily values. As such, these emission rates have been averaged over the sum of both operating and non-operating periods (most emission sources experience some down time during the year, usually for maintenance purposes). Although estimates of typical emission rates during operating periods are not presented in the inventory, these values may be readily determined using available process production data and the presented emission factors.

The emissions data base comprises 565 sources of SO_2 emissions and 4025 sources of NOx emissions. In total, 1945.2 t/d of SO_2 and NOx emissions were inventoried, 1267.0 t/d of SO_2 and 678.2 t/d of NOx. The petroleum industry is by far the major source, accounting for approximately 38% of NOx emissions and 82% of SO_2 emissions. Other important sources are electric power plants (NOx and SO_2 emissions), highways (NOx emissions), and urban centres (NOx emissions).

Overall, it was determined that the majority of the SO_2 and NOx emissions (approximately 1398.0 t/d or 71.9% of the total) occur in the southern half of the province where industrial activity is greatest. Although numerous sources of these pollutants were identified, the total provincial emission of SO_2 and NOx is dominated by a few large sources rather than many smaller sources. The ten highest emitters of SO_2 account for 61.2% of the total SO_2 emissions, and the ten highest emitters of NOx account for 38.5% of the total NOx emissions.

The developed inventories have been computerized using a microcomputer-based data management system. The system chosen for this purpose was dBase III, a popular and powerful industry-standard database package that is designed for IBM and compatible computers. To assist users who may not be familiar with dBase III, a special application program named AAESI (an acronym for Alberta Atmospheric Emission Source Inventories) has been developed.

In addition to development of the three inventories that comprised this study, there are a number of other projects that are being conducted as part of the ADRP. One of these projects is a comprehensive air quality monitoring (AQM) program, involving three AQM stations. One AQM station is for the measurement of "background" air quality of air entering Alberta and is situated in the Fortress Mountain ski area of the Kananaskis Valley in the Rocky Mountains, 70 km west of Calgary, Alberta. The remaining two AQM stations are located 40 km north of Calgary on agricultural land near Crossfield, Alberta. One of the AQM stations is located west of Crossfield to assess air quality after the air has entered the Province of Alberta and been altered by regional scale emissions. The second AQM station is located southeast of Crossfield and is influenced by emissons from many sources such as Highway 2, City of Calgary, City of Airdrie, Town of Crossfield, two mushroom factories, and several sour gas (extraction) plants. A detailed survey of the incinerator stack from the sour gas plant closest to the second AQM station was included as part of the source sampling survey program conducted.

Documentation of the developed inventories is presented in four volumes. Volume 1, Overview of the Emission Data, comprises a brief summary describing development of the inventory, a summary of emissions data by emission type, geographic region, industrial category and ecoregion, a comparison with results of previous inventories, and a summary of the air quality monitoring station inventory. Conclusions and recommendations are also presented in this volume. Detailed summary tables describing emissions by major source category, petroleum industry facility type, and source type for each geographic emission region are appended to the volume.

Volume 2, Design of the Emission Inventory, presents detailed information on the classification systems, source characterization, emission calculations, and data fields employed for each emission type. Details describing the source sampling program conducted as part of the NOx inventory and the computerization of the inventories are also presented in this volume. Furthermore, a detailed discussion of some of the major air quality monitoring networks in Alberta is included.

Volume 3, Emission Data Base, is a complete printout of the three inventories.

Volume 4, Results of the Emission Source Surveys, presents detailed results of the surveys conducted as part of the emissions inventory.

This Executive Summary is common to all volumes.

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1. INTRODUCTION

This volume has been prepared to provide scientific and non-scientific readers with an overview of the Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta. Section 2 comprises a brief description of the design of the sulphur dioxide (SO_2), nitrogen oxides (NOx) and air quality monitoring station inventories, and of the development of the computer-based data management system.

Section 3 comprises an overview of the emission data. Emission summaries by emission type, geographical region, industry category, and ecoregion type are presented. Section 3 also includes a ranking of the top ten sources of SO_2 and NOx emissions in Alberta, a comparison of this inventory with previously developed inventories, and a summary of the inventory of air quality monitoring stations.

Section 4 presents conclusions and recommendations of the overall study.

A comprehensive set of tables summarizing emissions by source category, facility type and source type are appended to this volume in Section 6. Sources of both SO_2 and NOx emissions are noted in these tables.

2. DEVELOPMENT OF THE INVENTORIES

Three comprehensive inventories were developed as part of this study, specifically:

- a sulphur dioxide (SO_2) emission inventory,
- a nitrogen oxides (NOx) emission inventory, and
- an inventory of air quality monitoring stations.

The rationale and methods employed in the development and computerization of these inventories are briefly described below.

2.1 SULPHUR DIOXIDE EMISSION INVENTORY

The inventory of sulphur dioxide (SO_2) emissions in Alberta identifies all SO_2 emission sources licenced by Alberta Environment, and all sour oil batteries approved by the Alberta Energy Resources Conservation Board (ERCB) that emit SO_2 at a rate of 0.2 tonnes per day (t/d) or more.

In order to catalogue the identified SO_2 emissions in an organized manner, the individual emission sources have been classified according to:

1. location, based on Alberta's legal land system (Legal Subdivision, Section, Township, Range),
2. environmental setting (surrounding vegetation type and ecoregion type),
3. type of source (incinerator, flare, dehydration unit, coal-fired boiler),
4. source characteristics (stack height and diameter, base elevation, stack gas temperature, exit gas velocity, and operating mode), and
5. type of facility with which the source is associated and industry sector with which the facility is associated (see Table 1).

Administrative data, including facility name, operator name, ERCB approval number, and Clean Air Act Licence number, are also documented for each source.

To characterize the rate at which SO_2 is emitted from a given source, emission data and relevant operating data would, ideally, be readily available for that individual source. However, such data are normally difficult to obtain or are unavailable. As a result, certain simplifying assumptions were made.

As a first approximation, it could have been assumed that actual emissions are, on average, equal to the maximum design or licenced values. However, it has been observed during the development of this inventory that actual SO_2 emissions are, in general, significantly lower than the licenced values (typically between one third and two thirds of the licenced values).

Consequently, to estimate the average emission rates for each source, emission factors have been employed. Where available, actual emission data have been used to determine these emission factors. Otherwise, emission factors were estimated based on values determined for similar sources. To indicate the quality of the emission factors that have been estimated or evaluated, the precision of each was determined.

Table 1. SO_2 inventory: types of industry sectors and facilities.

Industry	Facility
1. Chemical	Chemical Plant
2. Electric Utilities	Power Generation Plant
3. Fertilizer	Fertilizer Plant
4. Petroleum	Sour Gas (Extraction) Plant[1]
	Sour Gas (Flaring) Plant[1]
	Oil Battery
	Oil Sands Plant
	Heavy Oil Recovery Plant
	Refinery
5. Pulp and Paper	Pulp and Paper Mill

[1] Sour gas (extraction) plants are facilities where sulphur is recovered from the raw gas stream and only a small quantity of residual sulphur is incinerated. Sour gas (flaring) plants are facilities where all sulphur in the inlet gas is flared or incinerated.

2.2 NITROGEN OXIDES EMISSION INVENTORY

The inventory of NOx emissions has been divided into three separate sections, according to the type of source. These sections are:

- industrial sources,
- urban centre sources, and
- highway sources.

The NOx emissions from each source have been quantitatively expressed in terms of equivalent amounts of NO_2.

Since the characteristics of each of the above NOx emission source categories are quite different, three different inventory formats have been used, as described below.

The inventory of industrial NOx emission sources includes:

- all NOx emission sources currently licenced to operate under the Clean Air Act, and
- all NOx emission sources approved by ERCB that have a maximum rated power output of 100 kW or more.

Industrial NOx emission sources that have a maximum rate power output of less than 100 kW were excluded as detailed documentation of these sources is generally difficult to obtain and because total NOx emissions from these lesser sources are insignificant relative to total NOx emissions from the larger industrial sources. Proof of this latter point is provided in Section 3.5.2 where the total estimated NOx emissions due to the industrial sources inventoried is shown to compare favourably with the Alberta Environment (1984) estimate of total NOx emissions due to all industrial sources in the province.

Basic classification systems and methods used for estimating NOx emissions are essentially the same as those previously described for SO_2 emissions. Industrial source categories and facility types for NOx sources are listed in Table 2. Types of sources for NOx emissions are boilers, heaters, kilns, engines, and process units from nitric acid plants.

Except for certain of the larger sources (i.e., coal-fired boiler units and nitric acid plants), NOx emission monitoring is generally not conducted in Alberta. As a result, only limited data were available for use in developing NOx emission factors. In order to minimize reliance on U.S. Environmental Protection Agency (EPA) emission factors, and to address concerns that the use of these might not properly reflect typical operating and environmental conditions in Alberta, a limited NOx source sampling program was conducted.

A total of twenty-two NOx emission sources were surveyed as part of the source sampling program, twelve reciprocating engines, six turbine engines, and four waste gas incinerator units. An average NOx emission factor of 1075 ng/J was determined for the reciprocating engines. This value is approximately 27% lower than the value of 1481 ng/J published by the U.S. Environmental Protection Agency (1985). For turbine

Table 2. NOx inventory (industrial sources): types of industry sectors and facilities.

Industry	Facility
1. Cement	Cement Plant
2. Chemical	Chemical Plant
3. Electric Utilities	Power Generation Facility
4. Fertilizer	Fertilizer Plant
5. Petroleum	Sour Gas (Extraction) Plant
	Sour Gas (Flaring) Plant
	Oil Battery
	Oil Sands Plant
	Heavy Oil Plant
	Refinery
	Other Facilities[1]
6. Pulp and Paper	Pulp and Paper Mill

[1] Other Facilities include sweet gas plants, gas gathering and transmission compressors, and unspecified field facilities.

engines, an average NOx emission factor of 107 ng/J was obtained. This value is 15% lower than the value of 126 ng/J published by the U.S. Environmental Protection Agency (1985). The noted differences between the developed emission factors and the corresponding U.S. EPA values indicate that differences between typical operating and environmental conditions in Alberta and those in the United States may be significant in terms of their impact on NOx production by natural gas fueled engines. However, further testing is required to fully assess this.

The results from the survey of the four waste gas incinerator units indicate that the NOx emissions from a single unit will generally be no greater than that which may result from a 100 kW natural gas fueled reciprocating engine (roughly 0.03 t/d). Therefore, waste gas incinerator units were not, in general, considered to be noteworthy point sources of NOx emissions.

For urban centre sources, all villages, towns and cities in the province were included. Typically, a village is an urban centre which has a population of approximately 100 to 1000; a town has a population of approximately 1000 to 10,000; and a city has a population of approximately 10,000 or more. NOx emissions from urban centre sources have been attributed to vehicular traffic and to the residential, commercial and industrial consumption of natural gas.

For natural gas consumption, data provided by utility companies were used to establish per-capita use patterns in residential, commercial and industrial gas consumption. From these patterns, typical natural gas consumption figures were developed for each urban centre and, using published emission factors, average rates of NOx emissions were calculated. Based on previous research, NOx emissions from vehicular traffic were estimated based on the ratio of emissions resulting from space heating to those from vehicular traffic.

For highway sources, the three major sections of high traffic highways in the province were divided into a number of short segments and treated as line sources of NOx emissions. These sections consist of all of Highways 1 and 16, and Highway 2 from Westlock, located approximately 70 km north of Edmonton, south to the U.S. border. NOx emissions due to vehicular traffic on all other roadways, excluding urban roadways which are accounted for by the inventory of urban centre sources, were generally too low for these roadways to be treated as significant line sources (typically less than 0.005 t/d/km as compared with an average value of 0.06 t/d/km for highways).

For each highway segment, average daily vehicle volumes and vehicle type distribution data have been used along with NOx emission factors and average travelling speeds to calculate probable NOx emission rates.

Emission sources that have been excluded from the NOx inventory are:

1. industrial sources that have a total rated power output of less than 100 kW;
2. vehicular traffic outside of urban centres on roadways other than Highways 1, 2 and 16;
3. off-road vehicular traffic;
4. air and rail traffic;
5. natural gas consumption by summer villages and rural residences; and
6. forest fires.

These sources were excluded from the inventory because they were either too small and sparcely distributed, or too erratic (i.e., forest fires) to be characterized as local sources. The significance of the NOx emissions due to these additional sources is discussed in Section 3.5.2.

2.3 INVENTORY OF AIR QUALITY MONITORING STATIONS

The primary purpose of the NOx and SO_2 emission inventories is to provide a comprehensive and easy-to-use listing of emission information for the prediction of local and regional air quality. Once air quality predictions have been made, it is desirable to have actual air quality data for comparison. For this reason, the inventory of air quality monitoring stations in Alberta has been compiled. Only air quality monitoring stations in long-term monitoring programs, which are generally required as a condition of Clean Air Licences, have been inventoried. Those used in short-term or discontinued monitoring programs were excluded.

Air quality monitoring stations have been classified according to:

- location, based on Alberta's legal land system,
- monitoring programs (stack surveys, monitoring equipment and requirements, reporting frequencies),
- industry sector with which the station is associated, and
- operating parameters of the facility with which the station is associated (number of vent stacks, licenced emission rates).

Administrative data, including station and facility name, operator name, and Clean Air Act Licence number, were also documented for each station.

2.4 COMPUTERIZATION OF THE INVENTORIES

To manage the inventories, a data management system known as dBASE III was selected. dBASE III is currently one of the more powerful and popular data management systems available for microcomputer applications. It is designed for use by 16-bit microcomputers and runs on the IBM PC and compatibles.

One of the primary reasons for the selection of dBASE III is its ability to work with extremely large data files. The dBASE III data file may consist of over one billion records and each record may consist of up to 128 fields or be up to 4,000 characters long.

In comparison, many data management systems such as the popular LOTUS 1-2-3 and SYMPHONY are RAM-based (RAM is the acronym for random access memory) systems so that the maximum size of a data file is determined by the amount of active memory available. However, dBASE III, like many of the more powerful data management systems, transfers blocks of data back and forth between allocated active memory and the mass storage memory. In this way, the maximum data file size is essentially determined by the amount of mass storage available.

To simplify use of the inventories, a special application program, AAESI, has been developed (AAESI is the acronym for Alberta Atmospheric Emission Survey Inventory). Once activated, this program enables the user to work with the inventories by simply responding to menu selections that require a minimal knowledge of dBASE III.

3. OVERVIEW OF NOx and SO_2 EMISSIONS DATA

3.1 TOTAL NOx and SO_2 EMISSIONS

The emissions data base comprises 565 sources of SO_2 emissions, 4025 sources of industrial, urban, and highway NOx emissions, and 311 air quality monitoring programs. The number of data elements comprising the inventory is approximately 220,000 (Table 3).

Table 3. Size of the emissions data base.

Database Component	Number of Records[1]	Number of Fields[1]	Number of Elements[2]
SO_2 Emissions	565	48	27,120
NOx Industrial Emissions	3656	48	175,488
NOx Urban Emissions	245	13	3,185
NOx Highway Emissions	124	26	3,224
Air Quality Monitoring Stations[3]	311	35	10,885

[1] One record contains all data pertaining to a specific emission source or air quality monitoring station. A record consists of a number of discrete data fields.

[2] The number of elements is the product of the number of records and number of fields.

[3] Each record defines a single air quality monitoring program.

The emissions inventory encompassed the following parameters: (1) all significant industrial sources in Alberta, as defined in Section 2; (2) urban centres (all cities, towns, and villages); and (3) major highways. A map of Alberta is presented in Figure 1 showing major urban centres and major highways as well as the townships and ranges which are the basis of Alberta's legal land system; this system is described in Volume 2. Superimposed on Figure 1 is a grid defining the geographical regions used for the summarization of emissions data. Emission regions were selected to be approximately equivalent in geographic area, while allowing for:

- variances in order to locate similar types of emission sources in the same region (e.g., oil sands plants, chemical plants, power plants), and
- variances to accommodate the topographical grid system.

The Province of Alberta comprises a total area of 660,933 km^2 and spans a distance of approximately 1,220 km from north to south and over 650 km at the widest east-to-west transect. In Table 4 a summary of the ten emission regions by number is presented, showing the areal extent of each (km^2) and the percent of the area of Alberta occupied by each. Emission region 1 has the largest areal extent at 85,922 km^2 or 13.0% of the area of the province while emission region 4 has the smallest at 46,926 km^2 or 7.1% of the area of the province.

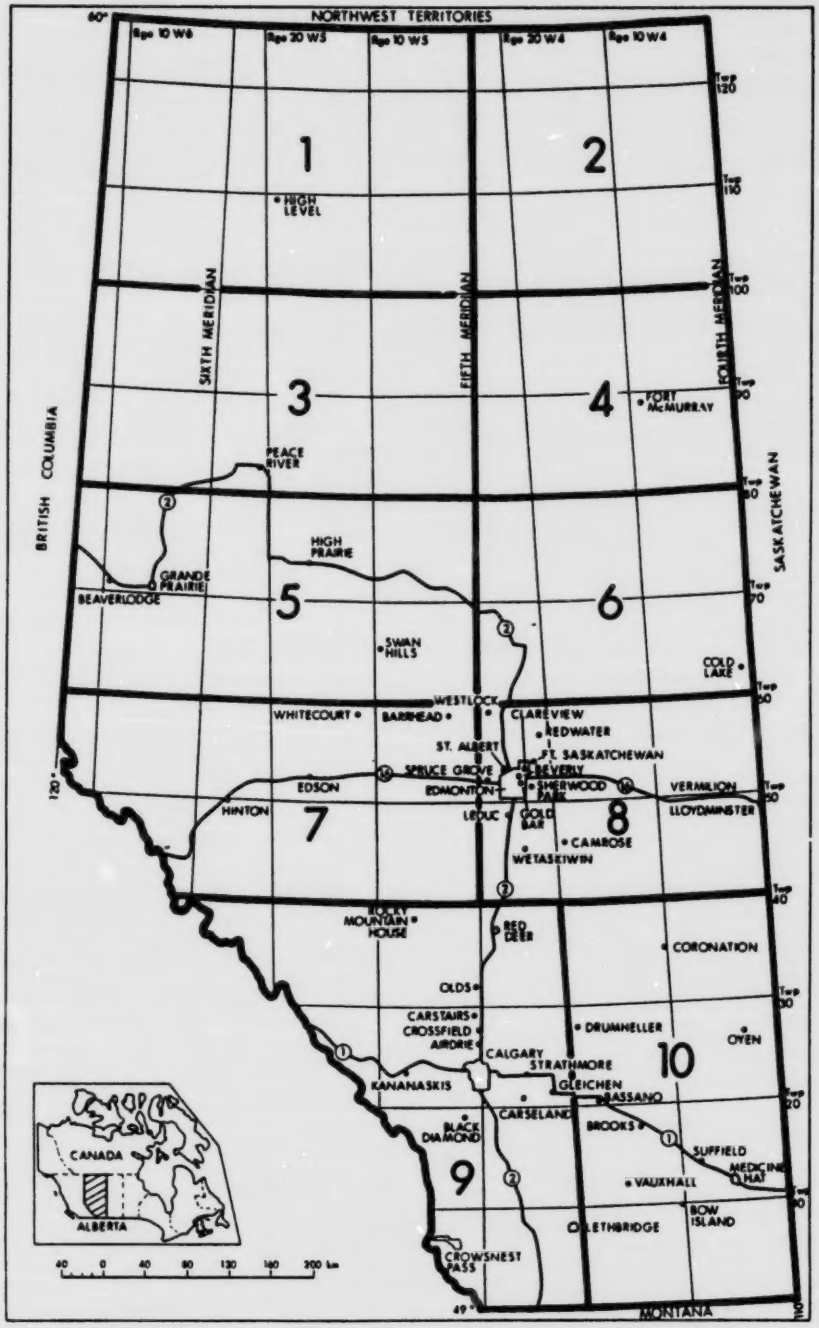

Figure 1. Map of Alberta showing major cities, and selected towns and villages and three major highways (1, 2, and 16) with respect to geographic emission regions used in summarizing the SO_2 and NO_x emissions data.

Table 4. Summary listing of the 10 emission regions of Alberta by number showing their areal extent (km^2) and percent of the area of Alberta occupied by each.

Emission Region	Area (km^2)	Area (%)
1	85,922	13.0
2	57,501	8.7
3	69,398	10.5
4	46,926	7.1
5	74,685	11.3
6	49,570	7.5
7	68,737	10.4
8	50,892	7.7
9	81,956	12.4
10	75,346	11.4
	660,933	

In total, 1945.2 t/d of SO_2 and NOx emissions were inventoried, 1267.0 t/d of SO_2 and 678.2 t/d of NOx. Emission sources were identified based on 1985-86 records available from government agencies and existing inventories (Alberta Environment 1984, 1985; Legge and Baker 1987). Emissions were estimated based on 1984 production, population and traffic data (Alberta Municipal Affairs 1985; Alberta Transportation 1985; and Energy Resources Conservation Board 1985a-1985d). Limited verification and updating of sources occurred in 1987.

Total SO_2 and NOx emissions by emission region are presented in Figure 2 as histograms superimposed on the Alberta map. Emission region 9, which includes the City of Calgary, has the highest total emissions (570.5 t/d). Other major sources in this region are two high traffic highways, several major sour gas processing plants, four fertilizer plants, and a cement plant.

Emission region 7, which includes four major coal-fired power plants, several major sour gas processing plants, and a pulp and paper mill, has the second highest emissions (493.6 t/d). Emission region 4, which includes two major oil sands plants, has the third highest emissions (385.5 t/d). Together, emission regions 9, 7, and 4 account for 75% of all emissions in the province.

Other regions with significant emissions are emission region 8 (the City of Edmonton, major highways, four refineries, and chemical and fertilizer plants), emission region 10 (power plants and oil and gas facilities), and emission region 5 (sour gas processing and a pulp and paper mill). Emission regions 1, 3, and 6 have a very low level of emissions (resulting primarily from oil and gas facilities) and emission region 2, which consists primarily of Wood Buffalo National Park, has no significant emissions.

Sulphur dioxide emissions are significantly higher than NOx emissions in most emission regions; this can generally be attributed to the extraction of sulphur from natural gas and the burning of sulphur-containing fuels in the province. It is only in the three emission regions, 6, 8 and 10, that NOx emissions are higher than SO_2 emissions. This results primarily from the lack of combustion of sulphur-containing fossil fuels in these regions.

It can be seen from Figure 2 that except for emission region 4, which contains two major oil sands plants, both NOx and SO_2 emissions in the northern half of the province (emission regions 1 to 6) are each considerably lower than in the southern half (emission regions 7 to 10). With respect to total provincial NOx and SO_2 emissions, 28.1% or 547.2 t/d occur in the northern half of the province and 71.9% or 1398.0 t/d occur in the southern half of the province. This is due to the presence and use of sulphur-containing fossil fuels and the heavy concentration of major industry, major urban centres, and major highways in the southern half of the province.

A pie chart depicting NOx and SO_2 emissions by major source category for the province is presented in Figure 3. The petroleum industry is the largest single contributor (as a source category) of both types of emissions, accounting for 38.0% of the NOx emissions (257.5 t/d) and 81.5% of the SO_2 emissions (1032.6 t/d). For this reason, both NOx and SO_2 emissions from various sectors of the petroleum industry are detailed later in Section 3.2. Electric power plants, highways, and urban centres are also important sources of NOx emissions representing 22.4, 15.9 and 15.7%, respectively, of total NOx emissions. Electric power plants are the second most important source of SO_2 emissions with 16.6% or 210.6 t/d of total SO_2 emissions.

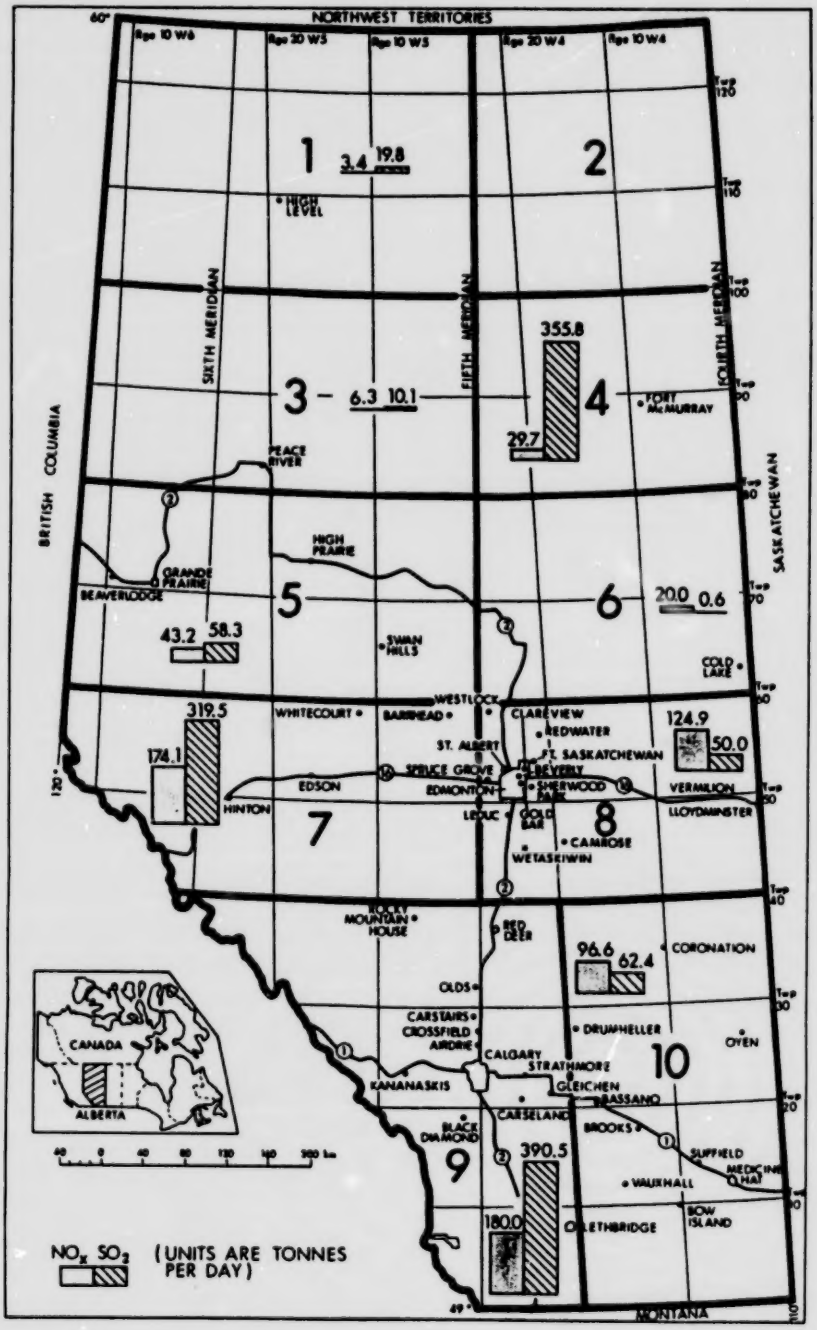

Figure 2. Map of Alberta showing total NO_x and total SO_2 emissions as histograms in each of the 10 geographical emission regions.

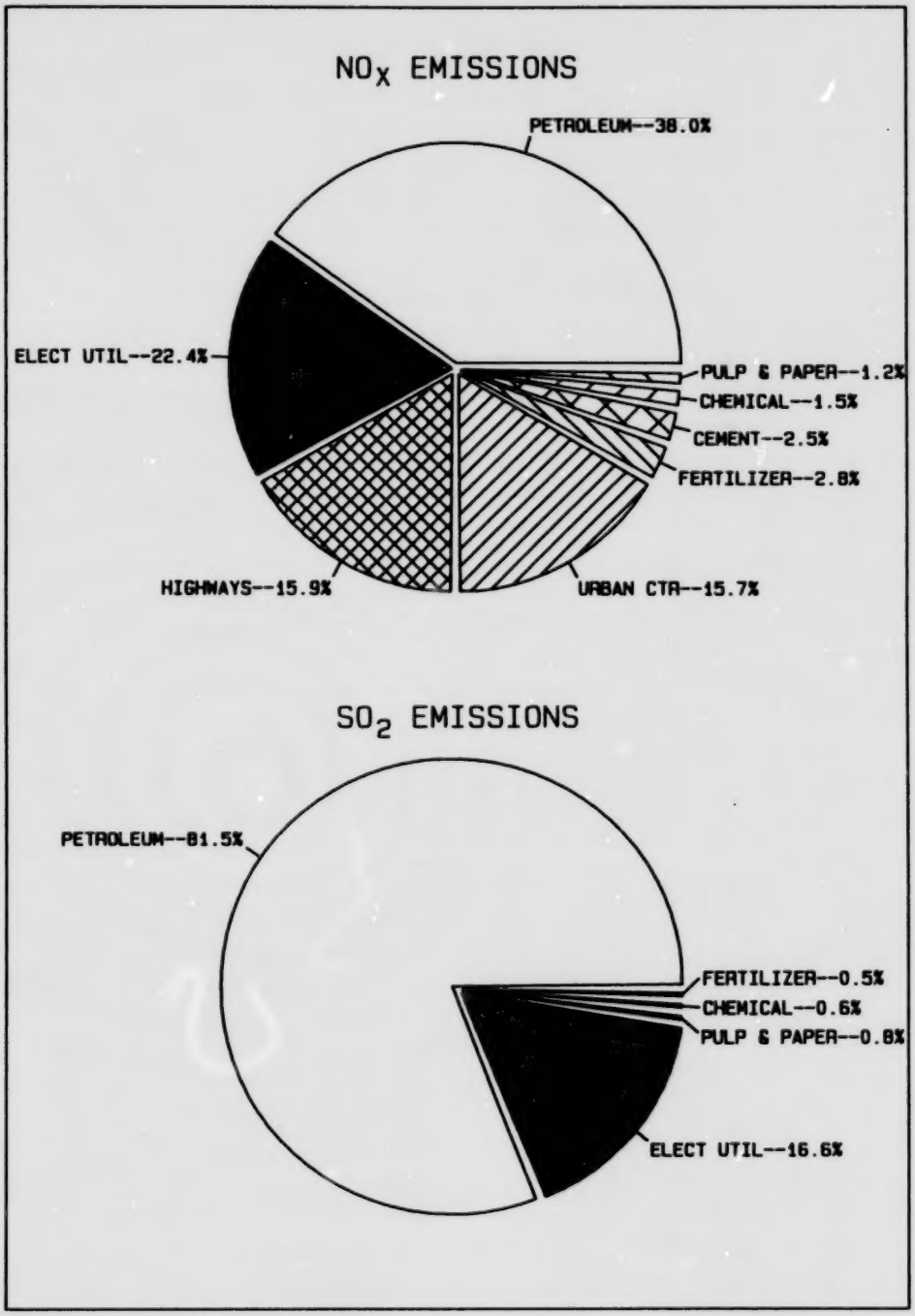

Figure 3. Total NO_x and total SO_2 emissions as a function of the percentage contribution by each major source category in Alberta.

A histogram showing NOx and SO_2 emissions for the province by major source category in tonnes per day is presented in Figure 4. Information on the number of sources (or population or highway length, where applicable) for each major emission source category and emission type is shown in parentheses.

Figure 5 presents histograms showing total NOx and SO_2 emissions by major source category as a function of each emission region. This figure is a breakdown by emission region of the total NOx and SO_2 histograms shown in Figure 4 and depicts the geographical patterns of emissions throughout the province as described previously. A detailed tabular breakdown of estimated emissions for each source category in each emission region is found in Tables 14 to 24 in Section 6.1.

3.2 PETROLEUM INDUSTRY SO_2 AND NOx EMISSIONS

A pie chart depicting NOx and SO_2 emissions from the petroleum industry as a function of the percentage contribution of each type of facility is presented in Figure 6; the corresponding emission rates are given by the histogram presented in Figure 7. Figure 7 also presents the number of facilities inventoried in each petroleum source category.

Sour gas (extraction) plants and oil sands plants are the two primary sources of SO_2 emissions, comprising 55.4% (572.4 t/d) and 34.5% (355.8 t/d) of petroleum industry SO_2 emissions, respectively. Other facilities, primarily gas gathering and transmission compressors, are the primary sources (67.5% or 173.7 t/d) of petroleum industry NOx emissions.

Control of SO_2 emissions from sour gas flaring plants has become an important public issue in many areas of Alberta. In view of this, it is of interest to note that such gas plants contribute only 4.5% of the total petroleum industry SO_2 emissions (Figure 6).

Figure 8 presents histograms showing petroleum industry NOx and SO_2 emissions by facility type as a function of emission region. Emission regions 9 and 4 have the highest SO_2 emissions due to the presence of sour gas processing facilities and oil sands plants, respectively. For emission regions 8, 9 and 10, which have the highest NOx emissions, the primary contributor is the "other facilities" category. This category is composed primarily of field compression facilities for the gathering and transmission of produced gas. Detailed data supporting Figure 8 are appended in Section 6.2 in Tables 25 to 35.

3.3 SO_2 AND NOx EMISSIONS BY ECOREGION

Since ecosystems vary in their sensitivity to air pollution, data for both NOx and SO_2 in the emission inventory were sorted according to the source location in each of the twelve ecoregions of Alberta as characterized by Strong and Leggat (1981). The term ecoregion is derived from "ecosystem" and "region" and is defined as an area characterized by a distinctive regional climate expressed by vegetation. The pattern of recurring vegetation, and soil and moisture sequences, was the main basis for the recognition and delineation of the ecoregions. Secondary successional species such as spruce (Picea) and fir (Abies) were used as additional criteria to separate ecoregions.

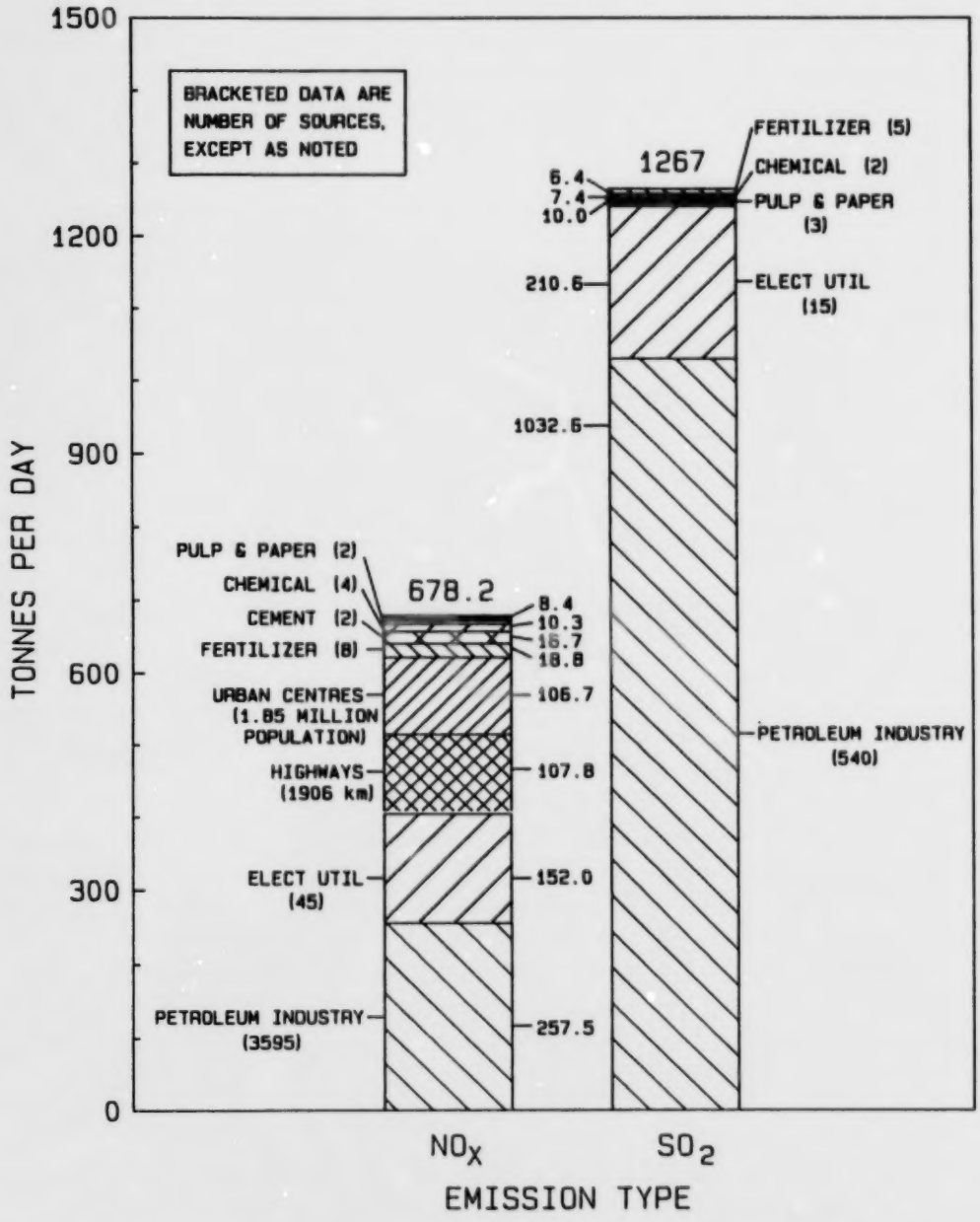

Figure 4. Total NO_x and total SO_2 emissions in Alberta by major source category.

Figure 5. Total NO_x and total SO_2 emissions by source category for each geographic emission region.

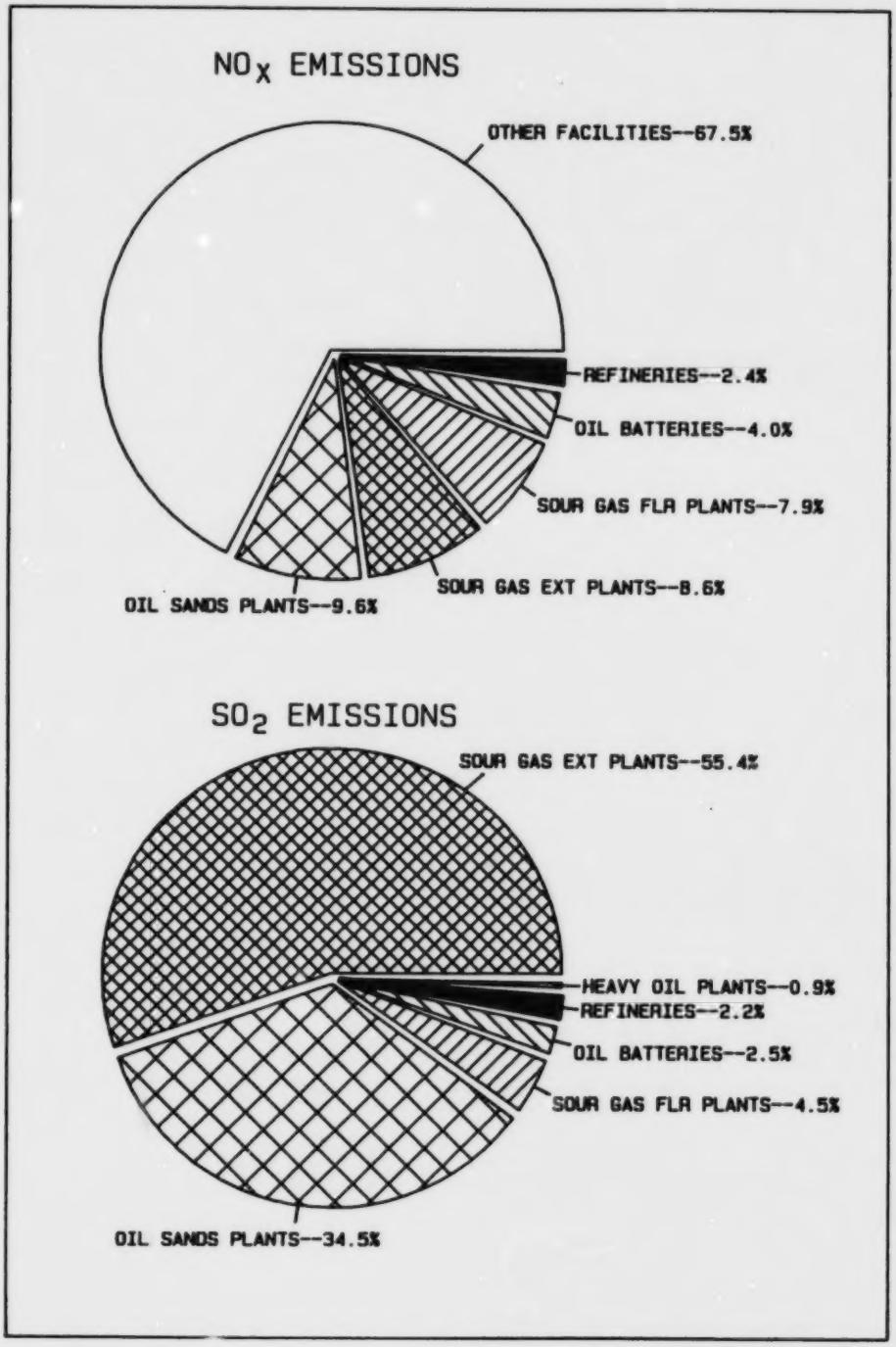

Figure 6. NO_x and SO_2 emissions from the Alberta petroleum industry as a function of the percentage contribution by each facility type.

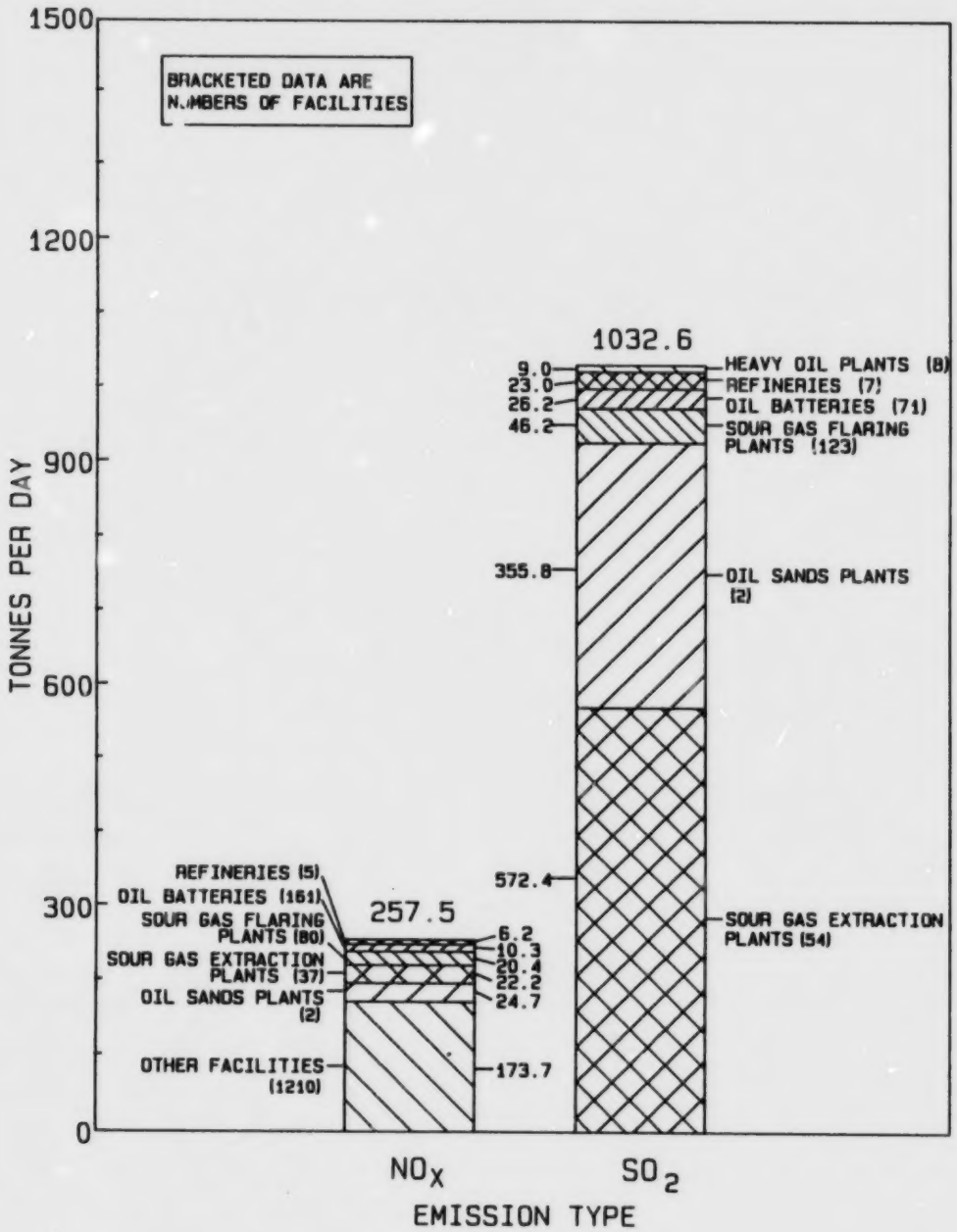

Figure 7. NO_x and SO_2 emissions from the Alberta petroleum industry as a function of facility type.

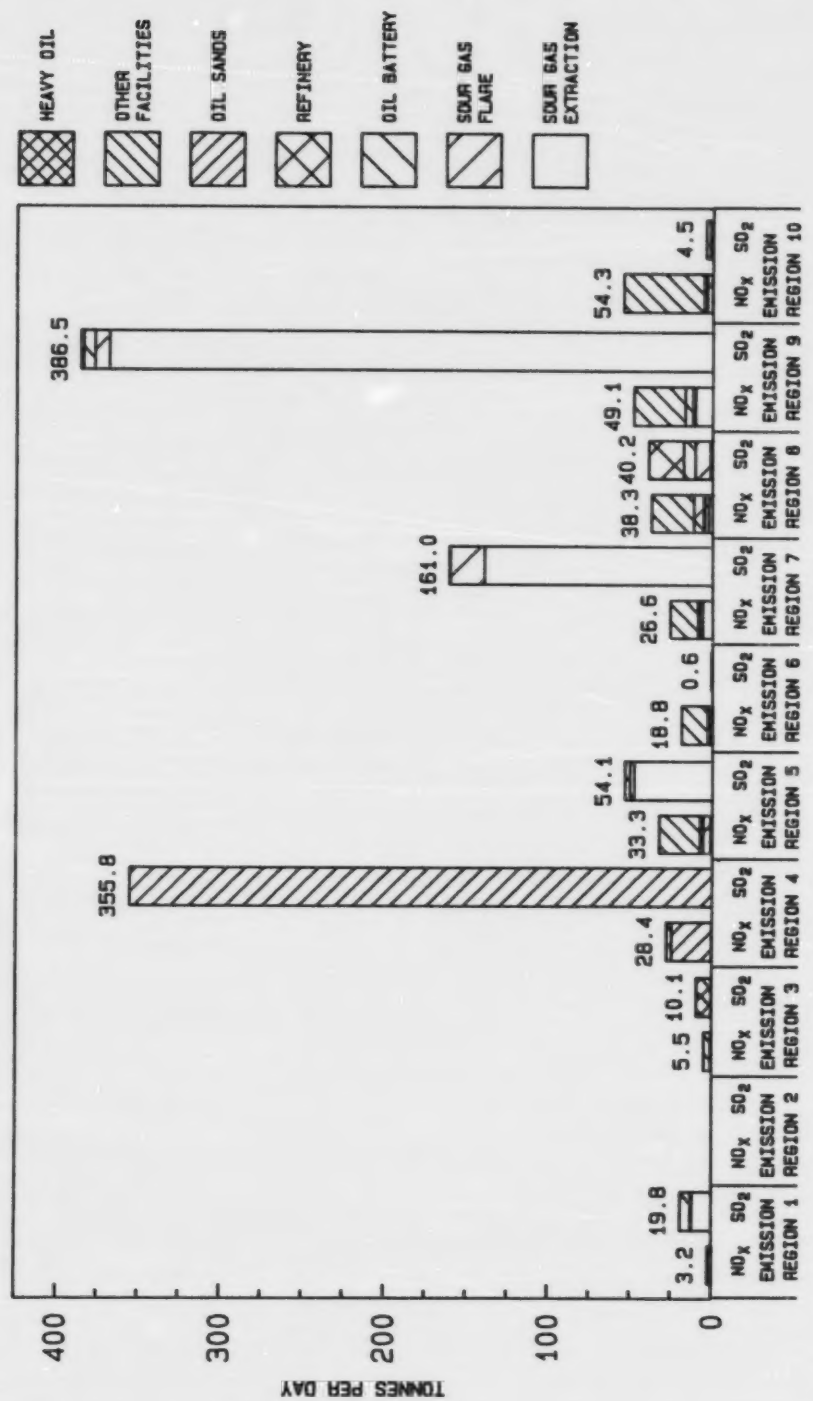

Figure 8. NO_x and SO_2 emissions by petroleum industry source type and geographic emission region.

Figure 9 is a map of Alberta showing the geographical distribution of the 12 ecoregions in Alberta. Table 5 is a summary listing of the twelve ecoregions of Alberta by name and number and shows the areal extent of each ecoregion (km^2) and the percent of the area of Alberta occupied by each ecoregion. The ecoregion with the largest areal extent is the boreal mixedwood (8) at 285,611 km^2 or 43.2% of the area of the province while the montane (5) ecoregion has the smallest areal extent at 3,538 km^2 or 0.5% of the area of the province.

A pie chart comparing combined NOx and SO_2 emissions by ecoregion to relative sizes of the ecoregions is presented in Figure 10. Three ecoregions, 4, 8 and 9, account for approximately 76.0% of emissions; these regions also comprise 63.9% of Alberta's land area. Ecoregions 3, 4, 5, 9, and 10 have relatively high emissions in comparison to their land areas, while ecoregions 1, 2, 6, 7, 8, 11 and 12 have comparatively low emissions. This point is more clearly seen in Table 6 where the average rate of combined NOx and SO_2 emission per unit land area (i.e., average emission flux) is given for each of the emission regions. The montane (5) ecoregion has by far the highest emissions per unit land area at 19.56×10^{-3} $t/d/km^2$, and the subalpine (6), boreal northlands (11), and boreal subarctic (12) ecoregions have the lowest at 0.11×10^{-3}, 0.14×10^{-3} and 0.12×10^{-3} $t/d/km^2$, respectively.

Figure 11 presents histograms for each ecoregion showing the relative levels of NOx and SO_2 emissions and Table 7 presents a summary of emission levels and numbers of sources for each ecoregion. Ecoregion 4 contains the largest number of industrial sources (976 sources of NOx and 172 sources of SO_2), urban centres (113) and length of major highway (669.3 km). Ecoregion 7 contains the fewest sources (4 sources of SO_2, no sources of NOx, no urban centres, and no major highway segments).

NOx emissions are higher than SO_2 emissions in ecoregions 1, 2, 4 and 6; SO_2 emissions are comparatively higher in the remaining eight ecoregions. Ecoregions with comparatively higher NOx emissions are the short and mixed grass (1 and 2) ecoregions and aspen parkland (4) ecoregion where the influence of urban centres and highways is important. Ecoregions with higher SO_2 emissions than NOx emissions are the fescue grass (3), boreal mixedwood (8), boreal foothills (9), and boreal uplands (10) ecoregions where sour gas processing is an important contributor to emission levels.

Figure 12 presents histograms showing total NOx and SO_2 emissions by major source category as a function of each ecoregion. This figure is a breakdown by ecoregion of the total NOx plus SO_2 histograms shown in Figure 11 and depicts the patterns of emissions by ecoregions throughout the province as discussed previously. A detailed tabular breakdown of emissions for each source category in each ecoregion is presented in Tables 47 to 58 in Section 6.4.

3.4 TOP-TEN RANKING OF EMISSION SOURCES

A ranked listing of the ten highest SO_2 emission sources in Alberta by emission region and ecoregion is presented in Table 8. Two oil sands plants dominate the list, accounting for 355.8 t/d of SO_2 emissions, or approximately 28.1% of the total provincial SO_2 inventory (1267.0 t/d). The other eight facilities on the list are power generation plants and sour gas (extraction) plants which account for 419.1 t/d or 33.1% of the total provincial SO_2 inventory. Although the 10 facilities represent

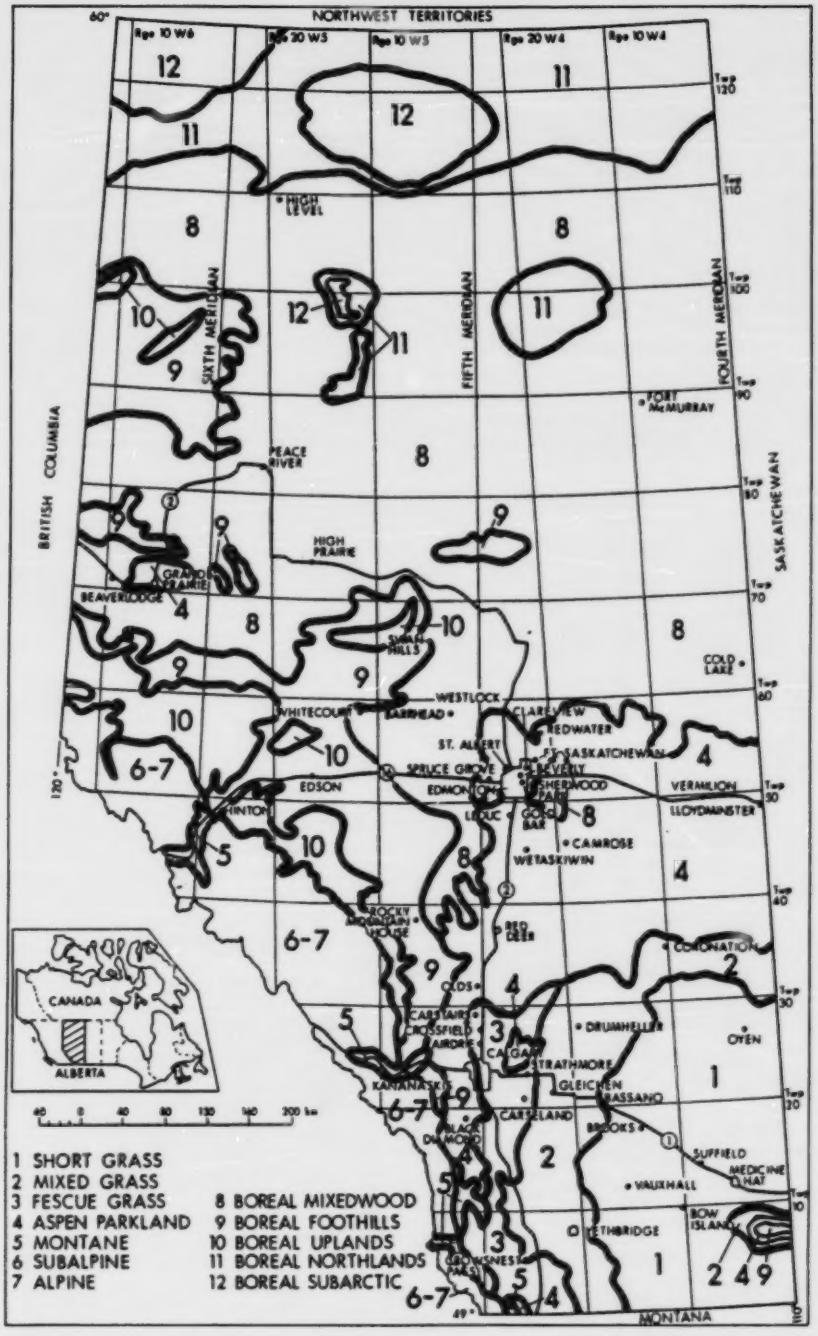

Figure 9. Map of Alberta showing ecoregions according to Strong and Leggat (1981) with respect to major urban centres and major highways.

Table 5. Summary listing of the 12 ecoregions of Alberta by name and number showing their areal extent (km²) and percent of the area of Alberta occupied by each (after Strong and Leggat 1981).

Ecoregion Name	Ecoregion Number	Area (km²)	Area (%)
Short Grass	1	46,926	7.1
Mixed Grass	2	31,063	4.7
Fescue Grass	3	14,403	2.2
Aspen Parkland	4	73,268	11.1
Montane	5	3,538	0.5
Subalpine	6	23,133	3.5
Alpine	7	18,506	2.8
Boreal Mixedwood	8	285,611	43.2
Boreal Foothills	9	63,362	9.6
Boreal Uplands	10	27,098	4.1
Boreal Northlands	11	47,588	7.2
Boreal Subarctic	12	26,437	4.0
TOTAL		660,933	100.0

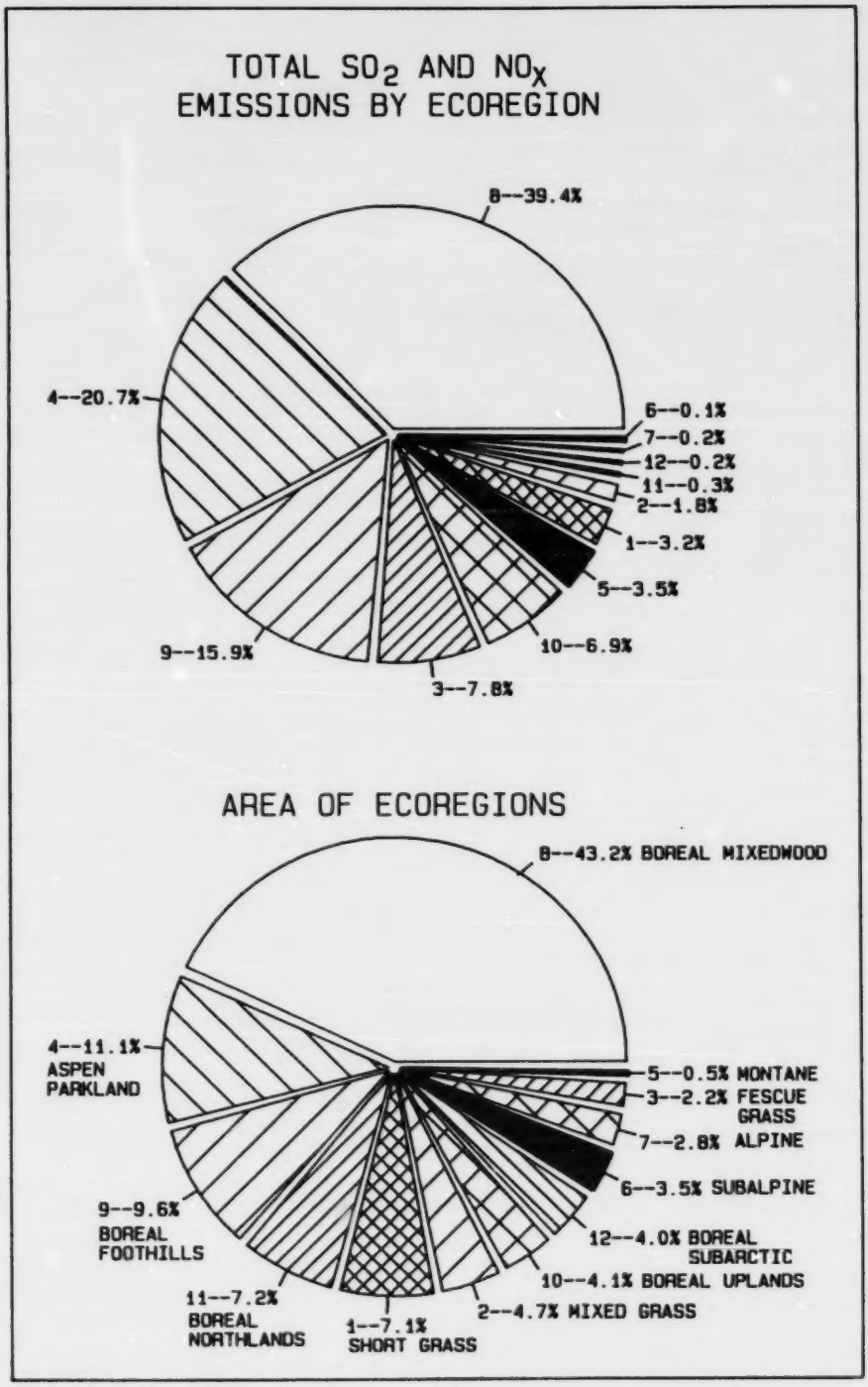

Figure 10. Comparison of total combined NO_x and SO_2 emissions within each ecoregion as a percentage of total NO_x and SO_2 emissions with the percentage of the total area of Alberta occupied by each ecoregion.

Table 6. Summary listing of the average rate of combined NOx and SO_2 emission per unit land area (i.e., average emission flux) as a function of ecoregion.

Ecoregion Name	Ecoregion Number	Area (km^2)	Combined SO_2 and NOx Emissions (t/d)	Average Emission Flux (10^{-3} t/d/km^2)
Short Grass	1	46,926	62.0	1.32
Mixed Grass	2	31,063	34.1	1.10
Fescue Grass	3	14,403	152.7	10.60
Aspen Parkland	4	73,268	401.8	5.48
Montane	5	3,538	69.2	19.56
Subalpine	6	23,133	2.6	0.11
Alpine	7	18,506	4.2	0.23
Boreal Mixedwood	8	285,611	766.4	2.68
Boreal Foothills	9	63,362	308.6	4.87
Boreal Uplands	10	27,098	133.8	4.94
Boreal Northlands	11	47,588	6.5	0.14
Boreal Subarctic	12	26,437	3.3	0.12

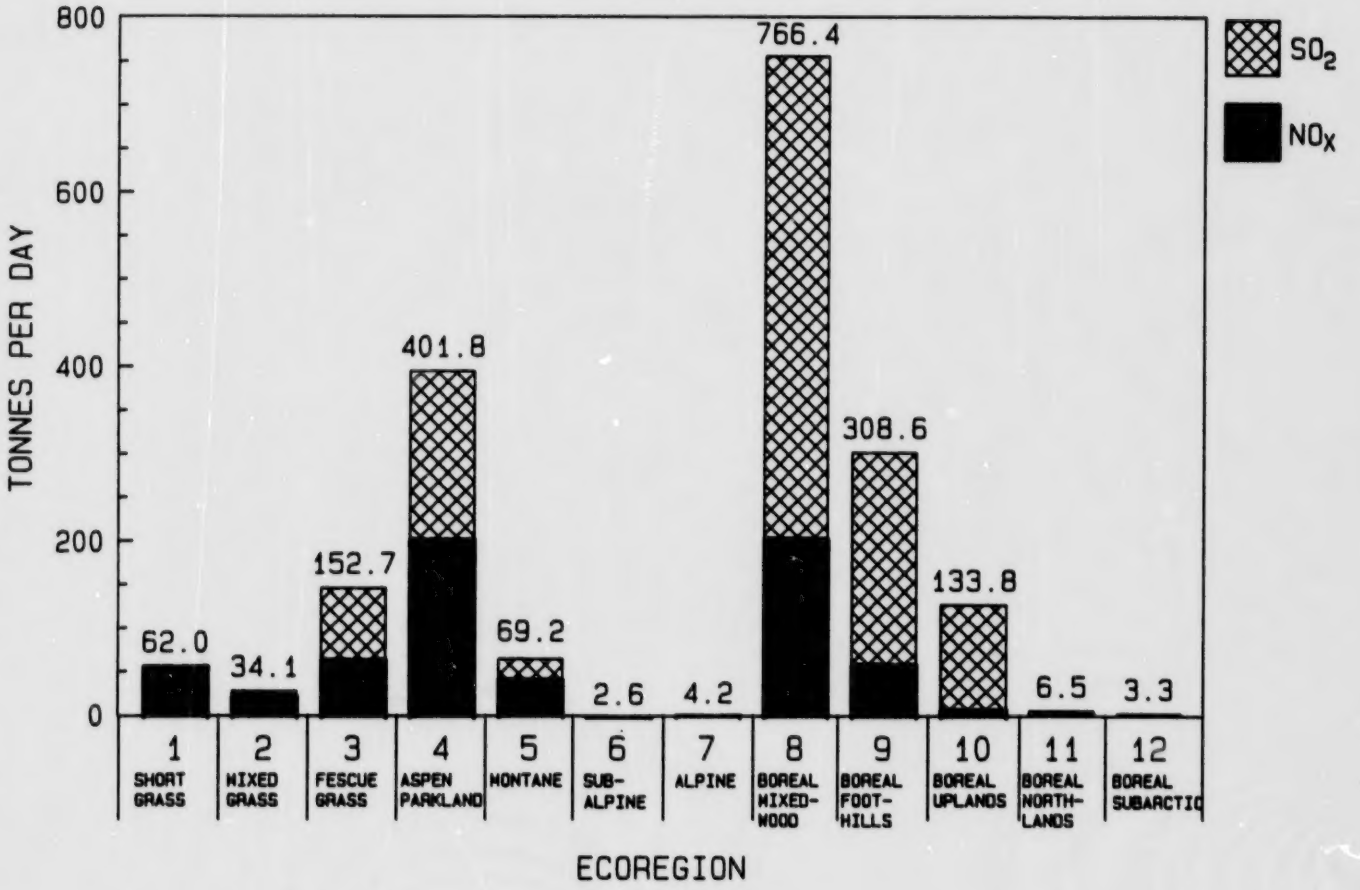

Figure 11. Total NO_x and SO_2 emissions by ecoregion.

Table 7. Summary of total provincial NOx and SO_2 emissions by ecoregion.

Ecoregion		NOx Emissions				SO_2 Emissions	
Name	Number	Total Emissions (t/d)	Number of Industrial Sources	Number of Urban Centres	Highway Segments (km)	Total Emissions (t/d)	Number of Sources
Short Grass	1	59.7	606	21	170.9	2.3	38
Mixed Grass	2	26.1	262	31	184.5	8.0	31
Fescue Grass	3	68.0	115	19	229.0	84.7	22
Aspen Parkland	4	206.8	976	113	669.3	195.0	175
Montane	5	28.7	16	1	252.7	40.5	6
Subalpine	6	2.6	11	2	0	0	2
Alpine	7	0	0	0	0	4.2	4
Boreal Mixedwood	8	212.0	770	47	111.1	554.4	134
Boreal Foothills	9	63.0	795	9	288.4	245.6	114
Boreal Uplands	10	10.9	96	2	0	122.9	20
Boreal Northlands	11	0.4	9	0	0	6.1	12
Boreal Subarctic	12	0	0	0	0	3.3	7

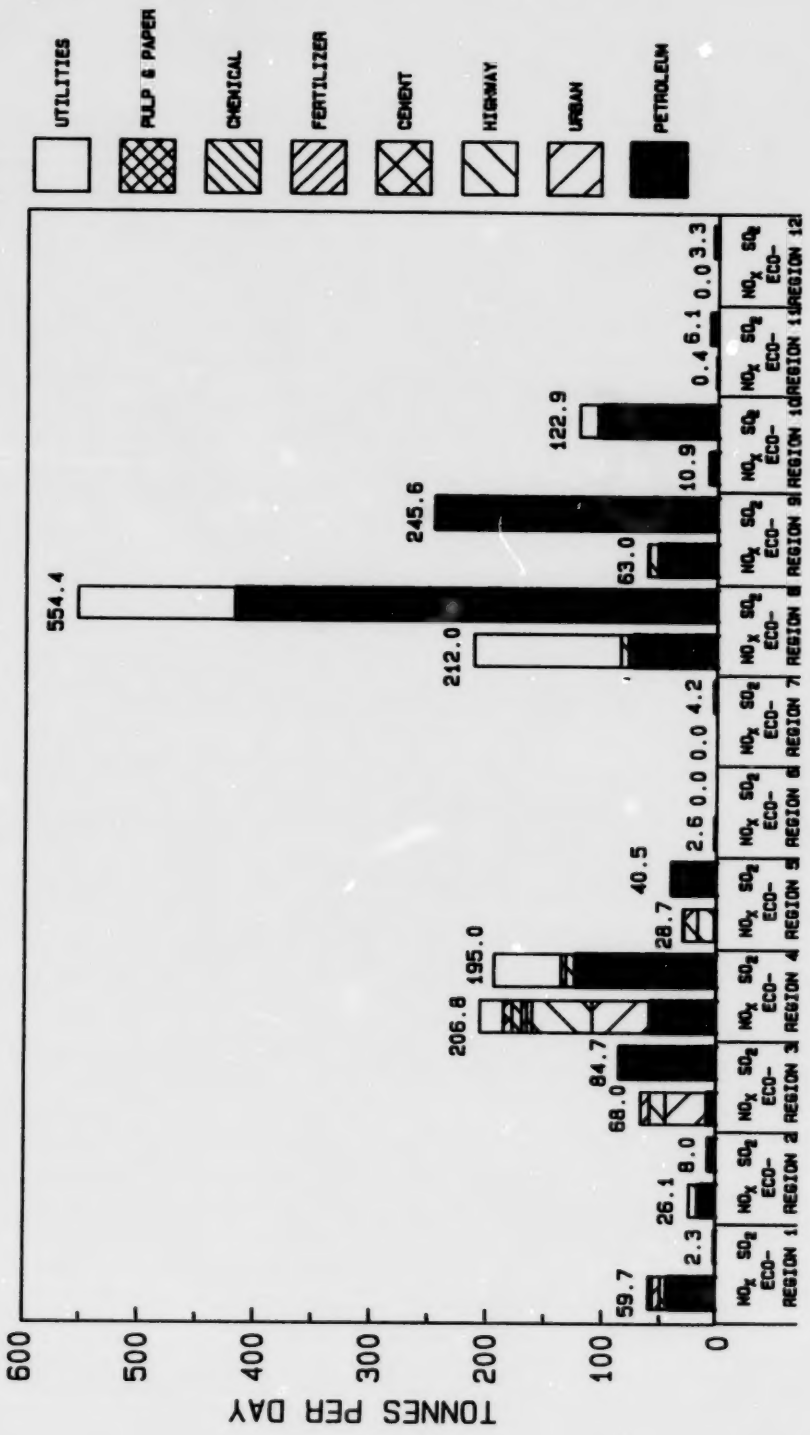

Figure 12. Total NO_x and SO_2 emissions by source category for each ecoregion.

Table 8. Ten highest SO_2 emission sources in Alberta.

Ranking	Description	Emission Region Number	Ecoregion Name	Ecoregion Number	SO_2 Emission Rate (t/d)
1	Oil Sands Plant	4	Boreal Mixedwood	8	194.2
2	Oil Sands Plant	4	Boreal Mixedwood	8	161.6
3	Sour Gas (Extraction) Plant	9	Boreal Uplands	10	85.5
4	Power Generation Plant	7	Boreal Mixedwood	8	81.0
5	Power Generation Plant	10	Aspen Parkland	4	57.9
6	Sour Gas (Extraction) Plant	7	Boreal Foothills	9	49.1
7	Sour Gas (Extraction) Plant	9	Fescue Grass	3	42.1
8	Sour Gas (Extraction) Plant	9	Aspen Parkland	4	35.1
9	Sour Gas (Extraction) Plant	7	Boreal Foothills	9	34.5
10	Power Generation Plant	7	Boreal Mixedwood	8	33.9
					774.9

only 2.1% of the total number of facilities listed in the SO_2 inventory (466), overall they account for 61.2% of the total SO_2 emissions. Total SO_2 emissions in Alberta are therefore dominated by a few large sources rather than by many smaller sources.

A ranked listing of the ten highest NOx emission sources in Alberta by emission region and ecoregion is presented in Table 9. A power generation plant dominates this list, accounting for 76.1 t/d of NOx emissions or approximately 11.2% of the total NOx inventory (678.2 t/d). This plant is followed in importance by the cities of Edmonton and Calgary and seven assorted industrial facilities. Although the 10 facilities and urban centres listed represent only 0.6% of total number of facilities and urban centres listed in the NOx inventory (1805), overall they account for 38.5% of the total NOx emissions (678.2 t/d). As was the case in the SO_2 inventory, the dominance of a few major sources is also evident in the NOx inventory.

A comparison of the ten highest SO_2 and NOx emission sources shown in Tables 8 and 9 reveals that five of the major sources of SO_2 emissions are also major sources of NOx emissions. These dual emission sources include the two oil sands plants and the three power generation plants. These five dual emission sources represent 41.7% or 528.6 t/d of total provincial SO_2 emissions and 22.9% or 155.5 t/d of total provincial NOx emissions. When SO_2 and NOx emissions from these five dual emission sources are combined, these five sources represent 35.2% or 684.1 t/d of the total provincial emissions.

An examination of Tables 8 and 9 also reveals a concentration of the ten highest SO_2 and NOx emission sources in relatively few geographic emission regions and ecoregions. Emission regions 4, 7 and 9 contain nine of the ten highest SO_2 emission sources (representing 717.0 t/d or 56.6% of the total SO_2 emissions inventory) and seven of the ten highest NOx emission sources (representing 169.6 t/d or 25.0% of total NOx emissions inventory). Ecoregions 3, 4, 8 and 9 contain nine of the ten highest SO_2 emission sources (representing 689.4 t/d or 54.4% of total SO_2 emissions inventory) and nine of the ten highest NOx emission sources (representing 249.3 t/d or 36.8% of total NOx emissions inventory).

3.5 COMPARISON WITH PREVIOUS INVENTORIES

To provide some verification of the developed SO_2 and NOx inventories, a comparison was made with the previous SO_2 and NOx inventories compiled by Alberta Environment (1985 and 1984, respectively). The results of this comparison are presented in the subsections to follow. For easy reference the developed inventories are referred to as the Acid Deposition Research Program (ADRP) inventories.

It is important to note that, although suitable for comparative purposes, the two inventories by Alberta Environment were developed using a different methodology than was used for the ADRP inventories, and serve a somewhat different purpose. The two ADRP inventories were basically developed using a differential approach. A differential approach is one in which individual point, line and area sources are identified and characterized. By using the differential approach, an emissions data base has been developed that is of sufficient detail to allow air quality predictions to be performed on a local or regional basis. As mentioned previously in Section 2, the emission rate for each of the sources identified has been estimated using emission factors.

Table 9. Ten highest NOx emission sources in Alberta.

Ranking	Description	Emission Region Number	Ecoregion Name	Ecoregion Number	NOx Emission Rate (t/d)
1	Power Generation Plant	7	Boreal Mixedwood	8	76.1
2	City of Edmonton	8	Aspen Parkland	4	36.5
3	City of Calgary	9	Fescue Grass	3	35.4
4	Power Generation Plant	7	Boreal Mixedwood	8	35.4
5	Power Generation Plant	10	Aspen Parkland	4	19.3
6	Power Generation Plant	7	Boreal Mixedwood	8	14.3
7	Oil Sands Plant	4	Boreal Mixedwood	8	13.2
8	Cement Plant	7	Montane	5	11.9
9	Oil Sands Plant	4	Boreal Mixedwood	8	11.5
10	Pulp and Paper Mill	5	Aspen Parkland	4	7.6
					261.2

Alberta Environment's inventories were developed by compiling average emission rate data available from industrial sources that continuously monitor their emissions as a condition of their Clean Air Act Licence to Operate (primarily SO_2 sources), by using appropriate emission factors and production data to estimate emissions from large industrial sources for which continuous emission monitoring data are unavailable (primarily NOx sources), and by using a lumped-analysis approach to estimate emissions from all other sources. A lumped-analysis approach is one in which all sources within a major source category or subcategory are lumped together and their average combined SO_2 or NOx emissions estimated by applying appropriate emission factors to per-capita and/or total provincial values of appropriate emission driving parameters (e.g., provincial statistics for fuel consumption, registered motor vehicles, etc.). Due to their partial reliance on the lumped-analysis approach and the fact that they do not fully characterize the individual sources that are identified (i.e., indicate their location in Alberta and provide physical details such as stack height and diameter), the Alberta Environment inventories do not provide sufficient detail to allow air quality predictions to be performed. As a result, the Alberta Environment inventories basically serve as an overview of the SO_2 and NOx emissions in Alberta.

3.5.1 Comparison of the SO_2 Inventory

The ADRP estimate for total SO_2 emissions in Alberta (1267.0 t/d; 1984 reference year) compares favourably with the Alberta Environment (1985) estimate of 1365.6 t/d (1983 reference year). The difference between the two estimates is only 98.6 t/d or 7.8% of the ADRP value.

Table 10 presents a comparison of the two SO_2 inventories by major source category. With the exception of oil batteries and sour gas (flaring) plants, agreement with respect to the different source categories is very good; the differences are typically less than 10% of the ADRP values. The relatively large discrepancy that occurs with respect to the oil batteries category (43.8 t/d or 167.2% difference) is attributed to the uncertainties associated with the two estimates. Alberta Environment's estimate for SO_2 emissions due to oil batteries is based on an actual 1981 value of 82.0 t/d provided by the Energy Resources Conservation Board (ERCB) and an assumed decline in this value of 6 t/d per year. The corresponding ADRP value is based on actual 1984 emission data provided by ERCB and, therefore, is considered to be the more accurate of the two.

The noteable discrepancy that occurs with respect to sour gas (flaring) plants (10.6 t/d or 29% difference) is attributed to uncertainty in the ADRP estimate (the Alberta Environment value for this category is based on a compilation of actual emission data). Although noteworthy, the impact of this discrepancy is insignificant relative to the estimated total provincial SO_2 emissions (i.e., only 0.8% of the ADRP estimate of 1267.0 t/d). The cause for uncertainty in the ADRP estimate is the relatively weak relationship between measured SO_2 emissions and available operating parameters for sour gas (flaring) plants; such relationships are required to develop the emission factors used by the inventory. Gas production proved to be the most suitable operating parameter for this purpose.

Table 10. Comparison of the ADRP SO_2 emission inventory with the Alberta Environment (1985) SO_2 emission inventory by major source category.

Source	ADRP Inventory[1] (t/d)	Alberta Environment Inventory[2] (t/d)	Difference[3] (t/d)	Difference[3] (%)
Chemical	7.4	7.4	0.0	0.0
Electric Utilities	210.6	195.2	-15.4	-7.3
Fertilizer	6.4	6.4	0.0	0.0
Petroleum:				
• Heavy Oil Plants	9.0	9.4	0.4	4.4
• Oil Batteries	26.2	70.0	43.8	167.2
• Oil Sands Plants	355.8	380.6	24.8	7.0
• Sour Gas (Extraction) Plants	572.4	607.0	34.6	6.0
• Sour Gas (Flaring) Plants	46.2	56.8	10.6	22.9
• Refineries	23.0	22.8	-0.2	-0.9
Pulp and Paper	10.0	10.0	0.0	0.0
	1267.0	1365.6	98.6	7.8

[1] Estimated emissions for the reference year 1984.

[2] Adapted from Alberta Environment (1985) for the reference year 1983 (the most current year available).

[3] With respect to the ADRP values.

The fact that the ADRP inventory predicts higher SO_2 emissions for the electric utilities category than does the Alberta Environment Inventory, reflects the increase in thermal electric power generation that occurred between 1983 and 1984 (ERCB 1985a), the respective reference years for the two inventories. Similarly, the generally lower SO_2 emissions predicted by the ADRP inventory for the petroleum category reflects the general decrease that occurred in oil and gas production between 1983 and 1984 (ERCB 1985c).

3.5.2 Comparison of the NOx Inventory

The total ADRP NOx emission inventory (678.2 t/d; 1984 reference year) compares only moderately well with the Alberta Environment (1984) estimate for total NOx emissions in Alberta (effectively 857.3 t/d, as noted in Table 11; 1982 reference year). The difference between the two estimated values is 179.1 t/d or 26.4% of the ADRP value. This notable difference is attributed to (1) the exclusion by the ADRP inventory (for practical reasons) of erratic (i.e., forest fires) and small sparsely-distributed sources (see Section 2.2), and (2) differences in the level of uncertainty in the two estimates.

Table 11 presents a comparison of the two NOx inventories by major sources category. In general, the two inventories compare favourably (less than 15% difference) with respect to the different source categories; however, relatively large discrepancies occur with respect to the electric utilities (36.7 t/d or 24.1% difference), highways (137.4 t/d or 127.5% difference), forest fires (32.1 t/d difference), and others (46.0 t/d difference) categories. Disagreement with respect to the electric utilities is attributed to the opening of a new coal-fired power plant and a general increase in thermal power generation between 1982 and 1984 (ERCB 1985a).

Disagreement with respect to the highways category, the major source of disagreement between the two inventories, is attributed in part to exclusion by the ADRP inventory of NOx emissions due to sparsely distributed traffic. Based on vehicle volume data compiled by Alberta Transportation (1985), the majority of the vehicular traffic that occurs outside of urban centres is concentrated on a few major highways (i.e., Highways 1, 2 and 16); the remainder of this traffic is sparsely distributed among the many other roadways in the province. As described in Section 2.2, the major portions of high traffic highway were divided into a discrete number of segments and treated as line sources of NOx. However, to apply this same approach to the sparsely distributed traffic was impractical due to the many thousands of kilometres of roadway in the province and the low NOx emissions for much of this roadway (i.e., typically 0.005 t/d or less per kilometre). Total NOx emissions unaccounted for due to exclusion of the sparsely distributed traffic is estimated, based on the Alberta Transportation (1985) vehicle volume data, to amount to approximately 65 t/d or 9.6% of the total ADRP NOx inventory (678.2 t/d).

The remaining 72.4 t/d discrepancy with respect to the highways category is attributed to the uncertainties associated with the two estimates. In the ADRP inventory, NOx emissions were estimated for the highways category by applying appropriate emission factors to traffic volume breakdowns (by vehicle class) for the major portions of Highways 1, 2 and 16. Alberta Environment used a lumped analysis approach in which total NOx emissions due to all vehicular traffic in the province (both inside and outside

Table 11. Comparison of the ADRP NOx emission inventory to the Alberta Environment (1984) NOx emission inventory by major source category.

Source	ADRP Inventory[1] (t/d)	Alberta Environment Inventory[2] (t/d)	Difference[3] (t/d)	Difference[3] (%)
Cement	16.7	16.7	0.0	0.0
Chemical	10.3	10.3	0.0	0.0
Electric Utilities	152.0	115.3	-36.7	-24.1
Fertilizer	18.8	19.9	1.1	5.9
Highways	107.8	245.2[4]	137.4	127.5
Petroleum	257.5	240.2[5]	-17.3	-6.7
Pulp and Paper	8.4	8.4	0.0	0.0
Urban Centres	106.7	123.2[4]	16.5	15.5
Forest Fires	0.0	32.1	32.1	-
Others[6]	0.0	46.0	46.0	-
	678.2	857.3	179.1	26.4

[1] Estimated emissions for the year 1984.

[2] Adapted from Alberta Environment (1984) for the reference year 1982, the most current year available.

[3] With respect to the ADRP values.

[4] The Alberta Environment value for total NOx emissions due to vehicular traffic (308.2 t/d) was prorated between the highways and urban centres categories by assuming that NOx emissions due to vehicular traffic in urban centres equals 2.83 times the NOx emissions due to residential and commercial consumption of natural gas (Western Research 1976a to b).

[5] To provide a common basis for comparison, Alberta Environment estimate for total NOx emissions by the petroleum category has been adjusted to reflect use of the developed Alberta-specific NOx emission factors for natural gas fueld reciprocating and turbine engines (1076 and 107 ng/J, respectively), as used in the ADRP inventory. The original Alberta Environment estimate for this category (351.6 t/d) was based on use of the corresponding emission factors (1481 and 126 ng/J, respectively) published by the U.S. Environmental Protection Agency (1981).

[6] Accounts for NOx emissions due to railway traffic and all small industrial facilities not already accounted for (primarily small chemical plants and remote diesel or natural gas fueled power plants).

urban centres) was estimated by applying appropriate emission factors and estimated average annual travelling distances to a breakdown (by vehicle class) of the total population of registered vehicles in Alberta (as indicated in Table 11, the Alberta Environment estimate for total NOx emissions due to vehicular traffic has been prorated accordingly between the highways and urban centres categories). To establish the more accurate of the two approaches is a matter for future investigation.

Disagreement with respect to the forest fires category (32.1 t/d) is due to the exclusion of forest fires by the ADRP inventory. The occurrence of forest fires was considered too erratic to allow forest fires to be predicted and characterized on a regional basis at a resolution consistent with the rest of the developed emissions data base. Exclusion of NOx emissions due to forest fires amounts approximately 4.7% of the total ADRP NOx inventory.

Disagreement with respect to the others category (46.0 t/d) is due to its exclusion by the ADRP inventory. The miscellaneous NOx emission sources accounted for by Alberta Environment in this category were considered to be too small and sparsely distributed for identification and characterization of the individual sources to be practical. Exclusion of NOx emissions due to the other categories amounts to approximately 6.8% of the total ADRP NOx inventory.

Overall, a total of 143.1 t/d of NOx emissions have been excluded from the ADRP inventory (i.e., 65 t/d due to sparsely distributed vehicular traffic, 32.1 t/d due to forest fires and 46.0 t/d due to other sources). The exclusion of this 143.1 t/d of NOx emissions amounts to approximately 21.1% of the total ADRP NOx inventory. If these additional emissions were included in the ADRP inventory, then disagreement with respect to the Alberta Environment estimate (857.3 t/d) would only be 36.0 t/d or 4.4% of the revised ADRP value (821.3 t/d).

It should be noted that the good agreement between the two NOx inventories with respect to the petroleum category (i.e., only 17.3 t/d or 6.7% difference) supports the assumption made in Section 2.2 that total NOx emissions due to industrial sources that have a maximum rated power output of less than 100 kW is insignificant relative to total NOx emission by all greater industrial sources.

3.6 AIR QUALITY MONITORING STATIONS

The inventory of air quality monitoring stations delineates long-term air quality monitoring programs that are conducted by industrial facilities as a condition of their Clean Air Act Licence to Operate. A total of 311 such programs are listed in the inventory. For each of these programs the amount and types of passive, manual and continuous monitoring conducted are indicated, and the frequency at which data are reported to Alberta Environment is noted. In general, all SO_2 emitting facilities listed previously in Table 1, except oil batteries which are relatively small sources, conduct air quality monitoring. With respect to NOx emission sources, all non-petroleum-industry facilities listed previously in Table 2 and refineries are required to conduct air quality monitoring.

Tables 12 and 13 present the number of air quality monitoring programs by geograhic emission region and by ecoregion. Emission regions 5 and 7 account for 152 or 48.9% of the 311 inventoried monitoring programs, while ecoregions 4 and 8 account for 197 or 63.3% of the inventoried programs.

Table 12. Number of air quality monitoring programs by geographic emission region.

Emission Region	Number of AQM Programs
1	6
2	1
3	15
4	34
5	81
6	31
7	71
8	37
9	26
10	9
	311

Table 13. Number of air quality monitoring programs by ecoregion.

Ecoregion	Number of AQM Programs
1	22
2	11
3	26
4	103
5	4
6	1
7	0
8	94
9	44
10	5
11	1
12	0
	311

In addition to the inventoried air quality monitoring stations, there are three air quality monitoring networks in Alberta; one (a continuous monitoring network) is operated by the Strathcona Industrial Association, and the other two (a continuous monitoring network and a passive and intermittent monitoring network) by Alberta Environment. The Strathcona network is located around the industrial area of east Edmonton and the County of Strathcona. The Alberta Government networks are located primarily in the cities of Calgary and Edmonton, but also include limited continuous monitoring in Fort McMurray, and limited passive and intermittent monitoring in selected small urban centres and around selected rural industrial operations. A detailed description of all three networks is presented in Volume 2.

In Volume 2 there are also descriptions of the climatological data collection activities by Alberta Government agencies, and a description of the three precipitation quality monitoring networks currently operating within Alberta.

The majority of the climatological data collected by Alberta Government Agencies are reported to Environment Canada. A catalogue is published by Environment Canada (1981), which identifies the climatological stations reporting to it and the types of data that these contain.

The three precipitation monitoring networks in Alberta consist of the Precipitation Quality Monitoring Network (PQMN), the Air Precipitation and Air Chemistry Program (APACP) operated by Alberta Environment, and the Alberta portion of the nation-wide Canada Air and Precipitation Monitoring Network (CAPMoN) operated by Environment Canada. The PQMN consists of ten stations located throughout the province, the APACP consists of a single station located at High Prairie, and the Alberta portion CAPMoN consists of one station located at Esther, a small rural community located approximately 40 km northeast of Oyen.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The conclusions of this study are as follows:

1. The emissions data base comprises 565 sources of SO_2 emissions and 4025 sources of NOx emissions. An estimate of the average rate of emission is provided for each of these sources. In total, 1945.2 t/d of SO_2 and NOx emissions were inventoried, 1267.0 t/d of SO_2 and 678.2 t/d of NOx. The SO_2 value is considered to be an accurate estimate of total SO_2 emissions in Alberta; however, the NOx value is estimated to be low by approximately 143.1 t/d or 21.1%. This additional 143.1 t/d of NOx emissions is due to emission sources that were excluded from the inventory because they were either small and sparsely distributed, or too erratic (i.e., forest fires) to be characterized on a local basis. These excluded sources consist of sparsely distributed vehicular traffic (i.e., vehicular traffic occurring outside of urban centres and away from major highways) (65 t/d), railway traffic and small industrial facilities (primarily small chemical plants and remote diesel or natural gas fueled power plants) (46.0 t/d) and forest fires (32.1 t/d).

2. The majority of the SO_2 and NOx emissions in Alberta (approximately 1398.0 t/d or 71.9% of the total) occur in the southern half of the province.

3. The total provincial emission of SO_2 and NOx is dominated by a few large sources rather than many smaller sources. The ten highest emitters of SO_2 account for 61.2% of the total SO_2 emissions inventory, and the ten highest emitters of NOx account for 36.2% of the total NOx emissions inventory.

4. The relative contribution of SO_2 emissions by major source category, from largest to smallest, is the petroleum industry at 81.5% (1032.6 t/d), the electric utilities industry at 16.6% (210.6 t/d), the pulp and paper industry at 0.8% (10.0 t/d), the chemical industry at 0.6% (7.4 t/d) and the fertilizer industry at 0.5% (6.4 t/d).

5. The relative contribution of NOx emissions by major source category, from largest to smallest (based on the emissions inventoried), is the petroleum industry at 38.0% (257.5 t/d), the electric utilities industry at 22.4% (152.0 t/d), highways at 15.9% (107.8 t/d), urban centres 15.7% (106.7 t/d), the fertilizer industry at 2.8% (18.8 t/d), the cement industry at 2.5% (16.7 t/d), the chemicals industry at 1.5% (10.3 t/d), and the pulp and paper industry at 1.2% (8.4 t/d).

6. A limited source sampling program was conducted in order to determine Alberta-specific NOx emission factors for natural gas fueled reciprocating and turbine engines, and to assess the importance of waste gas incinerator units as NOx emission sources. An average NOx emission factor of 1075 ng/J was determined for the reciprocating engines and a value of 107 ng/J was determined for the turbine engines. These values are 27 and 15% lower than the corresponding values of 1481 ng/J and 107 ng/J published by the U.S. Environmental Protection Agency (EPA) (1985). The differences between these two sets of emission factors are attributed to differences between the typical operating and environmental conditions in Alberta and those in the United States; however, further testing is required to fully assess this.

   For waste gas incinerator units, it was determined that the NOx emission rate for a single unit will typically be 0.03 t/d or less. Based on this value, waste gas incinerator units are insignificant sources of NOx emissions.

4.2 RECOMMENDATIONS

Major recommendations arising from this study are as follows:

1. The developed inventories described in this report will be of great value to government agencies, industry, and the academic community. In addition to being an efficient means of obtaining input data for air quality predictions, they can be used to conduct general emission audits and to readily identify regions of high emissions. It is therefore recommended that the inventories be made available to the above-mentioned groups.

2. In developing the inventories, information has been obtained from a number of different sources. These have included existing inventories, Alberta Environment, Energy Resources Conservation Board, and operating companies. As would be expected, some of the collected information was available from more than one of the sources mentioned. Therefore, as a means of quality control, the collected information was cross-referenced between the different sources. A number of inconsistencies were observed. All major inconsistencies were resolved. The minor inconsistencies (e.g., exact power ratings, stack dimensions and licenced emission rates), however, were too numerous to be fully addressed. It is therefore recommended that each operating company be sent a listing of the emission sources it operates, for validation. This would also be an effective means of completing information gaps (complete data sets were not available for all emission sources) and at the same time making the inventories known.

3. Because the inventories are time-dated it is recommended that a specific group or agency be charged with the responsibility of maintaining these in a current state.

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6. APPENDICES

6.1 Emissions by Major Source Category by Emission Region
6.2 Emissions by Petroleum Industry Facility Type by Emission Region
6.3 Emissions by Source Type by Emission Region
6.4 Emissions by Major Source Category by Ecoregion

6.1 EMISSIONS BY MAJOR SOURCE CATEGORY BY EMISSION REGION

NOx and SO_2 emissions by major source category for emission regions 1 through 10 are presented in Tables 14 to 23. Table 24 is a summary of emissions by major source category for all emission regions.

These tables provide total emissions in tonnes per day for NOx and SO_2 sources for each geographic emission region and for the province. Numbers of sources in the emission region are presented for industrial emissions. The number of urban centres with the corresponding emission region urban population is presented for NOx urban centre emissions while the length of highway within each emission region that was included in the inventory is presented for NOx highway emissions.

These tables form the basis for summary information presented in graphical form in Section 3.1 of this Volume.

Table 14. Emissions by major source category: emission region number 1.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	0	0
Petroleum	3.179	60	19.786	28
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	0	0	0	0
Towns	0.205	2 [3662]	0	0
Villages	0	0	0	0
Highways				
1, 2 or 16	0	0	0	0

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 15. Emissions by major source category: emission region number 2.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	0	0
Petroleum	0	0	0	0
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	0	0	0	0
Towns	0	0	0	0
Villages	0	0	0	0
Highways				
1, 2 or 16	0	0	0	0

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 16. Emissions by major source category: emission region number 3.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	0	0
Petroleum	5.478	101	10.121	16
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	0	0	0	0
Towns	0.729	4 [13027]	0	0
Villages	0.092	3 [1638]	0	0
Highways				
1, 2 or 16	0	0	0	0

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 17. Emissions by major source category: emission region number 4.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	0	0
Petroleum	28.353	47	355.810	14
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	1.371	1 [35352]	0	0
Towns	0	0	0	0
Villages	0	0	0	0
Highways				
1, 2 or 16	0	0	0	0

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 18. Emissions by major source category: emission region number 5.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	0	0
Petroleum	33.266	534	54.126	66
Pulp and Paper	7.562	1	4.200	1
Urban Centres				
Cities	0.947	1 [24411]	0	0
Towns	1.227	11 [21931]	0	0
Villages	0.172	8 [3088]	0	0
Highways				
1, 2 or 16	0	0	0	0

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 19. Emissions by major source category: emission region number 6.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	0	0
Petroleum	18.843	243	0.558	30
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	0	0	0	0
Towns	1.024	5 [18312]	0	0
Villages	0.078	3 [1404]	0	0
Highways				
1, 2 or 16	0	0	0	0

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 20. Emissions by major source category: emission region number 7.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	130.722	17	152.689	10
Fertilizer	0	0	0	0
Petroleum	26.625	452	161.002	85
Pulp and Paper	0.822	1	5.800	2
Urban Centres				
Cities	0	0	0	0
Towns	2.130	8 [38142]	0	0
Villages	0.297	9 [5318]	0	0
Highways				
1, 2 or 16	13.456	366.1		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 21. Emissions by major source category: emission region number 8.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	4.739	1	0	0
Chemical	6.063	2	7.400	2
Electric Utilities	0.916	15	0	0
Fertilizer	0.436	2	2.400	3
Petroleum	38.341	516	40.209	76
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	39.827	5 [630858]	0	0
Towns	5.210	30 [93206]	0	0
Villages	0.811	42 [14461]	0	0
Highways				
1, 2 or 16	28.580	484.1 km	0	0

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 22. Emissions by major source category: emission region number 9.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	11.945	1	0	0
Chemical	2.230	1	0	0
Electric Utilities	0	0	0	0
Fertilizer	11.632	4	4.000	1
Petroleum	49.120	759	386.540	147
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	42.231	4 [739901]	0	0
Towns	4.477	34 [92229]	0	0
Villages	0.632	31 [12939]	0	0
Highways				
1, 2 or 16	57.706	798.1	0	0

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 23. Emissions by major source category: emission region number 10.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	1.978	1	0	0
Electric Utilities	20.317	13	57.948	5
Fertilizer	6.758	2	0	1
Petroleum	54.276	883	4.426	78
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	2.614	2 [48164]	0	0
Towns	2.231	16 [45866]	0	0
Villages	0.395	26 [8191]	0	0
Highways				
1, 2 or 16	8.025	257.6	0	0

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 24. Emissions by major source category: all emission regions.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	16.684	2	0	0
Chemical	10.271	4	7.400	2
Electric Utilities	151.955	45	210.637	15
Fertilizer	18.826	8	6.400	5
Petroleum	257.481	3595	1032.578	540
Pulp and Paper	8.384	2	10.000	3
Urban Centres				
Cities	86.990	13 [1478686]	0	0
Towns	17.233	110 [326375]	0	0
Villages	2.477	122 [47039]	0	0
Highways				
1, 2 or 16	107.767	1905.9 km	0	0

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

6.2 EMISSIONS BY PETROLEUM INDUSTRY FACILITY TYPE BY EMISSION REGION

NOx and SO_2 emissions by petroleum industry facility type for geographic emission regions 1 through 10 are presented in Tables 25 through 34. Table 35 is a summary of emissions by petroleum industry facility type for all emission regions.

These tables provide total emissions in tonnes per day for NOx and SO_2 petroleum industry sources in each geographic emission region and for the province. Facilities that are significant sources of both NOx and SO_2 emissions are listed. Numbers of facilities in each emission region are also presented.

These tables form the basis for summary information presented in graphical form in Section 3.2 of this Volume.

Table 25. Emissions by petroleum industry facility type: emission region number 1.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	0.316	1	12.636	2	3.754	1
Sour Gas (Fl) Plants	0.099	1	0.794	3	0.099	1
Oil Batteries	0.052	4	6.356	19	1.327	3
Oil Sands Plants	0	0	0	0	0	0
Heavy Oil Plants	0	0	0	0	0	0
Refineries	0	0	0	0	0	0
Other Facilities	2.712	21	0	2	0.561	2

Note: Ex = Extraction
Fl = Flaring

Table 26. Emissions by petroleum industry facility type: emission region number 2.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	0	0	0	0	0	0
Sour Gas (Fl) Plants	0	0	0	0	0	0
Oil Batteries	0	0	0	0	0	0
Oil Sands Plants	0	0	0	0	0	0
Heavy Oil Plants	0	0	0	0	0	0
Refineries	0	0	0	0	0	0
Other Facilities	0	0	0	0	0	0

Note: Ex = Extraction
Fl = Flaring

Table 27. Emissions by petroleum industry facility type: emission region number 3.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	0	0	0	0	0	0
Sour Gas (Fl) Plants	0.911	6	1.121	7	0.975	6
Oil Batteries	0.304	4	0	1	0.156	1
Oil Sands Plants	0	0	0	0	0	0
Heavy Oil Plants	0	1	9.000	1	9.000	1
Refineries	0	0	0	0	0	0
Other Facilities	4.263	37	0	7	1.680	7

Note: Ex = Extraction
Fl = Flaring

Table 28. Emissions by petroleum industry facility type: emission region number 4.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	0	0	0	0	0	0
Sour Gas (Fl) Plants	0.574	2	0	4	0.574	2
Oil Batteries	0	0	0	0	0	0
Oil Sands Plants	24.651	2	355.810	2	380.461	2
Heavy Oil Plants	0	3	0	3	0	3
Refineries	0	0	0	0	0	0
Other Facilities	3.128	13	0	2	0.200	1

Note: Ex = Extraction
Fl = Flaring

Table 29. Emissions by petroleum industry facility type: emission region number 5.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	0.717	4	48.468	8	8.992	4
Sour Gas (Fl) Plants	5.788	15	2.670	15	8.450	15
Oil Batteries	1.805	19	2.988	5	0	0
Oil Sands Plants	0	0	0	0	0	0
Heavy Oil Plants	0	0	0	0	0	0
Refineries	0	0	0	0	0	0
Other Facilities	24.956	116	0	27	3.620	22

Note: Ex = Extraction
Fl = Flaring

Table 30. Emissions by petroleum industry facility type: emission region number 6.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	0	0	0	0	0	0
Sour Gas (Fl) Plants	2.933	6	0.588	12	3.073	6
Oil Batteries	0.016	1	0	0	0	0
Oil Sands Plants	0	0	0	0	0	0
Heavy Oil Plants	0	4	0	4	0	4
Refineries	0	0	0	0	0	0
Other Facilities	15.894	123	0	10	1.900	9

Note: Ex = Extraction
Fl = Flaring

Table 31. Emissions by petroleum industry facility type: emission region number 7.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	6.948	7	139.858	13	117.598	7
Sour Gas (Fl) Plants	1.799	13	20.861	20	10.644	13
Oil Batteries	0.547	15	0.283	2	0.029	1
Oil Sands Plants	0	0	0	0	0	0
Heavy Oil Plants	0	0	0	0	0	0
Refineries	0	0	0	0	0	0
Other Facilities	17.331	115	0	30	4.041	27

Note: Ex = Extraction
Fl = Flaring

Table 32. Emissions by petroleum industry facility type: emission region number 8.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	3.368	4	2.413	4	5.781	4
Sour Gas (Fl) Plants	2.362	13	9.317	23	9.434	13
Oil Batteries	0.570	15	7.079	17	2.406	3
Oil Sands Plants	0	0	0	0	0	0
Heavy Oil Plants	0	0	0	0	0	0
Refineries	6.241	4	21.400	4	27.641	4
Other Facilities	25.800	246	0	20	2.551	17

Note: Ex = Extraction
Fl = Flaring

Table 33. Emissions by petroleum industry facility type: emission region number 9.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	10.747	20	369.021	27	224.503	20
Sour Gas (Fl) Plants	2.191	8	9.043	14	3.078	7
Oil Batteries	5.015	52	6.876	19	2.943	7
Oil Sands Plants	0	0	0	0	0	0
Heavy Oil Plants	0	0	0	0	0	0
Refineries	0	1	1.600	3	0	1
Other Facilities	31.167	184	0	46	4.706	37

Note: Ex = Extraction
Fl = Flaring

Table 34. Emissions by petroleum industry facility type: emission region number 10.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	0.122	1	0	0	0.122	1
Sour Gas (Fl) Plants	3.725	16	1.858	25	4.016	16
Oil Batteries	1.971	51	2.568	8	0.478	1
Oil Sands Plants	0	0	0	0	0	0
Heavy Oil Plants	0	0	0	0	0	0
Refineries	0	0	0	0	0	0
Other Facilities	48.458	385	0	41	5.810	40

Note: Ex = Extraction
Fl = Flaring

Table 35. Emissions by petroleum industry facility type: all emission regions.

Petroleum Industry Facility Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities	Total Emissions (t/d)	Number of Facilities
Sour Gas (Ex) Plants	22.218	37	572.396	54	360.75	37
Sour Gas (Fl) Plants	20.382	80	46.222	123	40.351	79
Oil Batteries	10.280	161	26.150	71	7.339	16
Oil Sands Plants	24.651	2	355.810	2	380.461	2
Heavy Oil Plants	0	8	9.000	8	9.000	8
Refineries	6.241	5	23.000	7	27.641	5
Other Facilities	173.709	1240	0.000	185	25.069	162

Note: Ex = Extraction
Fl = Flaring

6.3 EMISSIONS BY SOURCE TYPE BY EMISSION REGION

NOx and SO_2 emissions by source type for geographic emission regions 1 through 10 are presented in Tables 36 to 45. Table 46 presents a summary of emissions by source type for all emission regions.

These tables provide total emissions in tonnes per day for NOx and SO_2 sources for each geographic emission region and for the province. Six boiler units which are significant sources of both NOx and SO_2 emissions are noted. Numbers of sources in each emission region are also presented.

Table 36. Emissions by source type: emission region number 1.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	0.001	3	0	0	0	0
Heater Units	0	2	0	0	0	0
Nitric Acid Plants	0	0	0	0	0	0
Reciprocating Engines	3.178	34	0	0	0	0
Turbine Engines	0	0	0	0	0	0
Flares	0	0	8.576	26	0	0
Incinerator Units	0	0	11.210	2	0	0
Electric Motors	0	21	0	0	0	0
Kilns	0	0	0	0	0	0

Table 37. Emissions by source type: emission region number 2.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	0	0	0	0	0	0
Heater Units	0	0	0	0	0	0
Nitric Acid Plants	0	0	0	0	0	0
Reciprocating Engines	0	0	0	0	0	0
Turbine Engines	0	0	0	0	0	0
Flares	0	0	0	0	0	0
Incinerator Units	0	0	0	0	0	0
Electric Motors	0	0	0	0	0	0
Kilns	0	0	0	0	0	0

Table 38. Emissions by source type: emission region number 3.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	0.033	9	0	0	0	0
Heater Units	0.041	7	0	0	0	0
Nitric Acid Plants	0	0	0	0	0	0
Reciprocating Engines	5.322	82	0	0	0	0
Turbine Engines	0.082	3	0	0	0	0
Flares	0	0	10.121	16	0	0
Incinerator Units	0	0	0	0	0	0
Electric Motors	0	0	0	0	0	0
Kilns	0	0	0	0	0	0

Table 39. Emissions by source type: emission region number 4.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	24.653	10	135.400	1	146.9	1
Heater Units	0.003	3	0	0	0	0
Nitric Acid Plants	0	0	0	0	0	0
Reciprocating Engines	3.564	31	0	0	0	0
Turbine Engines	0.133	3	0	0	0	0
Flares	0	0	64.000	11	0	0
Incinerator Units	0	0	156.410	2	0	0
Electric Motors	0	0	0	0	0	0
Kilns	0	0	0	0	0	0

Table 40. Emissions by source type: emission region number 5.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	8.903	78	4.200	1	11.762	1
Heater Units	0.058	40	0	0	0	0
Nitric Acid Plants	0	0	0	0	0	0
Reciprocating Engines	29.450	347	0	0	0	0
Turbine Engines	2.417	53	0	0	0	0
Flares	0	0	9.781	58	0	0
Incinerator Units	0	0	44.345	8	0	0
Electric Motors	0	17	0	0	0	0
Kilns	0	0	0	0	0	0

Table 41. Emissions by source type: emission region number 6.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	0.028	21	0	0	0	0
Heater Units	0.000	1	0	0	0	0
Nitric Acid Plants	0	0	0	0	0	0
Reciprocating Engines	18.595	209	0	0	0	0
Turbine Engines	0.220	10	0	0	0	0
Flares	0	0	0.558	29	0	0
Incinerator Units	0	0	0	1	0	0
Electric Motors	0	2	0	0	0	0
Kilns	0	0	0	0	0	0

Table 42. Emissions by source type: emission region number 7.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	133.199	91	158.489	11	282.882	11
Heater Units	1.036	68	0	0	0	0
Nitric Acid Plants	0	0	0	0	0	0
Reciprocating Engines	22.044	265	0	0	0	0
Turbine Engines	1.890	19	0	0	0	0
Flares	0	0	22.725	72	0	0
Incinerator Units	0	0	138.277	13	0	0
Electric Motors	0	27	0	0	0	0
Kilns	0	0	0	1	0	0

Table 43. Emissions by source type: emission region number 8.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	0.958	44	0	0	0	0
Heater Units	0.119	17	0	0	0	0
Nitric Acid Plants	0	0	0	0	0	0
Reciprocating Engines	31.193	420	0	0	0	0
Turbine Engines	0.746	29	0	0	0	0
Flares	0	0	37.965	73	0	0
Incinerator Units	12.740	7	5.644	7	0	0
Electric Motors	0	18	0	0	0	0
Kilns	4.739	1	6.400	1	0	0

Table 44. Emissions by source type: emission region number 9.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	2.812	117	0	0	0	0
Heater Units	0.284	70	0	0	0	0
Nitric Acid Plants	3.353	2	0	0	0	0
Reciprocating Engines	44.372	495	0	0	0	0
Turbine Engines	3.882	45	0	0	0	0
Flares	0	0	20.841	119	0	0
Incinerator Units	8.279	2	369.699	29	0	0
Electric Motors	0	33	0	0	0	0
Kilns	11.945	1	0	0	0	0

Table 45. Emissions by source type: emission region number 10.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	20.364	92	57.948	5	0	0
Heater Units	0.061	40	0	0	0	0
Nitric Acid Plants	0	0	0	0	0	0
Reciprocating Engines	48.821	703	0	0	0	0
Turbine Engines	5.347	35	0	0	0	0
Flares	0	0	4.426	78	0	0
Incinerator Units	8.736	3	0	1	0	0
Electric Motors	0	26	0	0	0	0
Kilns	0	0	0	0	0	0

Table 46. Emissions by source type: all emission regions.

Emission Source Types	NOx Sources		SO_2 Sources		Sources of NOx and SO_2	
	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number	Total Emissions (t/d)	Number
Boiler Units	190.951	465	356.037	18	441.544	13
Heater Units	1.602	248	0	0	0	0
Nitric Acid Plants	3.353	2	0	0	0	0
Reciprocating Engines	206.539	2586	0	0	0	0
Turbine Engines	14.717	197	0	0	0	0
Flares	0	0	178.993	482	0	0
Incinerator Units	29.755	12	725.585	63	0	0
Electric Motors	0	144	0	0	0	0
Kilns	16.684	2	6.400	2	0	0

6.4 EMISSIONS BY MAJOR SOURCE CATEGORY BY ECOREGION

NOx and SO_2 emissions by major source category for ecoregions 1 through 12 are presented in Tables 47 to 58. No summary table is provided since it would be identical to Table 24 in Section 6.1.

These tables provide total emissions in tonnes per day for NOx and SO_2 sources for each ecoregion. Numbers of sources in the ecoregion are presented for industrial emissions. The number of urban centres with the corresponding ecoregion urban population is presented for NOx urban centre emissions while the length of highway within each ecoregion that was included in the inventory is presented for NOx highway emissions.

These tables form the basis for summary information presented in graphical form in Section 3.3 of this Volume.

Table 47. Emissions by major source category: ecoregion number 1.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	1.978	1	0	0
Electric Utilities	1.061	8	0	0
Fertilizer	6.758	2	0	1
Petroleum	41.353	595	2.271	37
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	2.298	1 [41493]		
Towns	1.110	7 [23448]		
Villages	0.228	13 [4260]		
Highways				
1, 2 or 16	4.954	170.9		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 48. Emissions by major source category: ecoregion number 2.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	1	0	1
Fertilizer	0	0	0	0
Petroleum	14.190	261	8.021	30
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	3.561	2 [65257]		
Towns	0.946	11 [26481]		
Villages	0.310	18 [7115]		
Highways				
1, 2 or 16	7.051	184.5		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 49. Emissions by major source category: ecoregion number 3.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	7.750	2	0	0
Petroleum	9.220	113	84.702	22
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	35.865	2 [630245]		
Towns	1.324	9 [24468]		
Villages	0.152	8 [3247]		
Highways				
1, 2 or 16	13.666	229.0		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 50. Emissions by major source category: ecoregion number 4.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	4.739	1	0	0
Chemical	8.293	3	7.400	2
Electric Utilities	20.172	19	57.948	4
Fertilizer	4.318	4	2.400	3
Petroleum	58.511	948	123.085	165
Pulp and Paper	7.562	1	4.200	1
Urban Centres				
Cities	42.948	6 [681928]		
Towns	7.610	51 [138256]		
Villages	1.056	56 [19186]		
Highways				
1, 2 or 16	51.532	669.3		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 51. Emissions by major source category: ecoregion number 5.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	11.945	1	0	0
Chemical	0	0	0	0
Electric Utilities	0.471	6	0	0
Fertilizer	0	0	0	0
Petroleum	0.370	9	40.492	6
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	0	0		
Towns	0.359	1 [7577]		
Villages	0	0		
Highways				
1, 2 or 16	15.576	252.7		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 52. Emissions by major source category: ecoregion number 6.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	0	0
Petroleum	1.472	11	0	2
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	0.947	1 [24411]		
Towns	0.190	1 [4012]		
Villages	0	0		
Highways				
1, 2 or 16	0	0		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 53. Emissions by major source category: ecoregion number 7.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	4.000	1
Petroleum	0	0	0.200	3
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	0	0		
Towns	0	0		
Villages	0	0		
Highways				
1, 2 or 16	0	0		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 54. Emissions by major source category: ecoregion number 8.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	125.696	10	136.851	9
Fertilizer	0	0	0	0
Petroleum	73.871	760	417.541	125
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	1.371	1 [35352]		
Towns	3.757	23 [67198]		
Villages	0.630	23 [11290]		
Highways				
1, 2 or 16	6.674	111.1		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 55. Emissions by major source category: ecoregion number 9.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	0	0
Petroleum	52.196	794	245.636	114
Pulp and Paper	0.822	1	0	0
Urban Centres				
Cities	0	0		
Towns	1.539	5 [27814]		
Villages	0.101	4 [1941]		
Highways				
1, 2 or 16	8.314	288.4		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 56. Emissions by major source category: ecoregion number 10.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	4.555	1	15.838	1
Fertilizer	0	0	0	0
Petroleum	5.930	95	101.246	17
Pulp and Paper	0	0	5.800	2
Urban Centres				
Cities	0	0		
Towns	0.398	2 [7121]		
Villages	0	0		
Highways				
1, 2 or 16	0	0		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 57. Emissions by major source category: ecoregion number 11.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	0	0
Petroleum	0.368	9	6.091	12
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	0	0		
Towns	0	0		
Villages	0	0		
Highways				
1, 2 or 16	0	0		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.

Table 58. Emissions by major source category: ecoregion number 12.

Emission Source Category	NOx Sources		SO_2 Sources	
	Total Emissions (t/d)	Number[1]	Total Emissions (t/d)	Number
Industries				
Cement	0	0	0	0
Chemical	0	0	0	0
Electric Utilities	0	0	0	0
Fertilizer	0	0	0	0
Petroleum	0	0	3.293	7
Pulp and Paper	0	0	0	0
Urban Centres				
Cities	0	0		
Towns	0	0		
Villages	0	0		
Highways				
1, 2 or 16	0	0		

[1] For urban centres, units are number of centres with population data provided in brackets. For highways, units are length in km.